WOODWORKER'S GUIDE TO

Bending Wood

TECHNIQUES, PROJECTS, AND EXPERT ADVICE FOR FINE WOODWORKING

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Contents

Figure i. Jonathan Benson, *End Table*, solid cherry and laminate-bent veneer, 2008.

Introduction

I began learning about woodworking by constructing objects that primarily consisted of straight lines, flat planes, and right angles. Working with straight lines is the best way to develop the skills to create objects from wood. When I began designing, I was drawn to curves. To me, curves complement the organic nature of wood. The grain pattern of most wood is not straight, but curvaceous and undulating, which seems to call for some sort of curve.

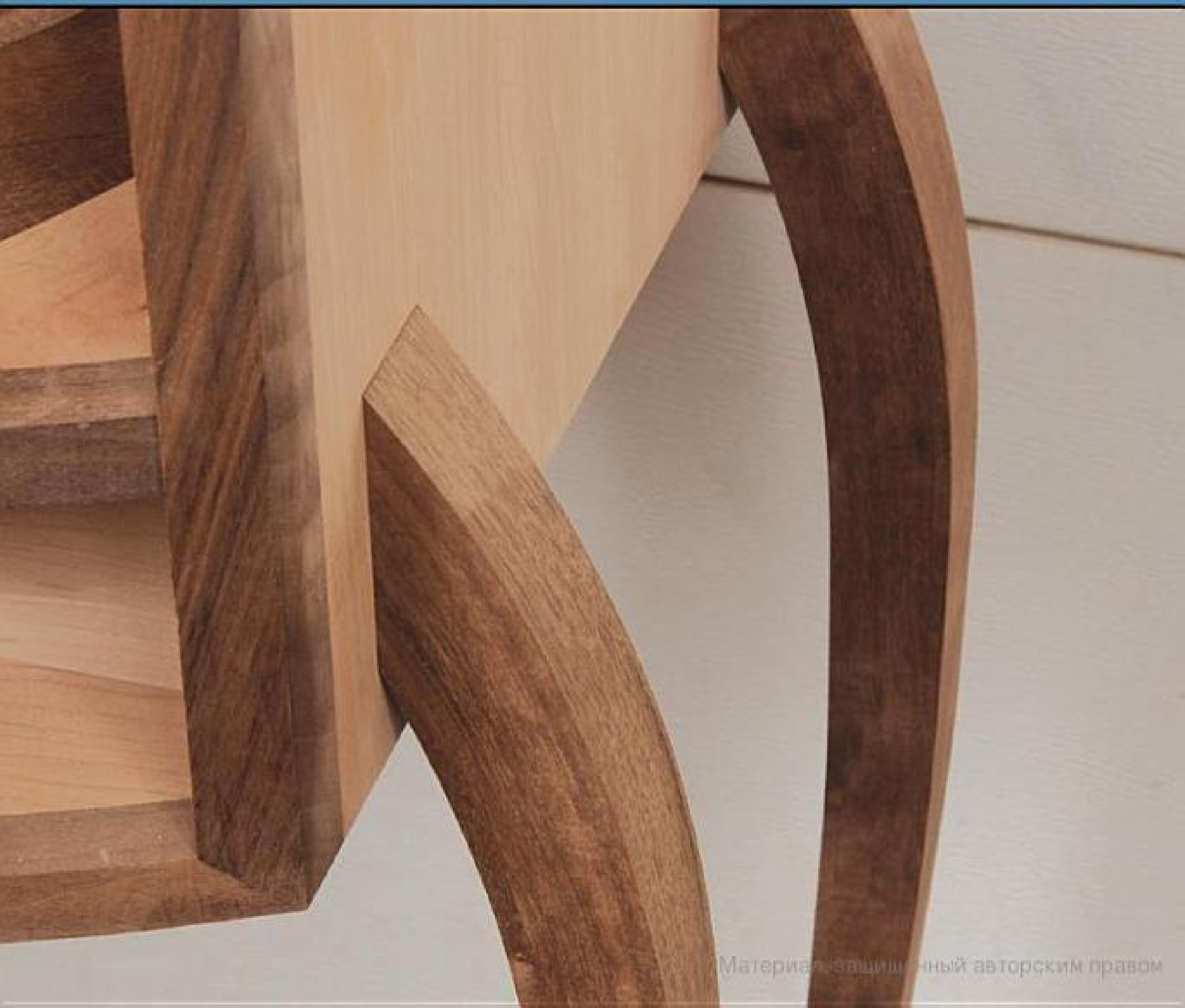
In my early designs, I took joinery techniques and applied them to more organic designs—taking large pieces of wood, creating joints, and cutting and carving shapes out of the wood. The projects were beautiful and sturdy but consumed a lot of wood. The size of the wood, its grain direction, the availability of a particular species in large size, and my budget limited the curves. For some projects, I still use this method, but for others, I incorporate bending.

Bending wood allows me to create designs I couldn't imagine before. While there are still limits, bending allows for more shapes and longer arcs, permits the use of fine veneers on the surface, and adds strength—while using less wood. Throughout this book, you will find many ways to bend wood and will see the advantages and disadvantages of each. If you have a particular shape in mind and it pushes the limits of one process too far, try using a different process to create the same shape.

This book will start out with a discussion of basic wood properties and how wood reacts to bending. Then, it will describe in detail the various bending techniques—from bending green wood by hand to gluing thin laminations to vacuum pressing complicated curves. You will learn to apply the techniques and the pros and cons of each. I will take the mystery out of bending and show how anyone with a little woodworking knowledge and a few basic tools can create beautiful curved designs.

—Jonathan Benson

Figure ii. Here's the top of the curved leg on the demonstration cabinet you'll be seeing throughout this book. The legs, drawer fronts, door rails and panels, and front edge banding are all bent laminations. The leg-to-case joint is a tenon reinforced with screws.



CHAPTER 1

Bending Wood Then and Now

Green, fresh-cut branches bend easily, making them useful for constructing bows, baskets, and boats. Much later, bent wood became a popular way to construct furniture, and the methods for bending and stabilizing projects have grown. Craftsmen have long chosen wood-bending techniques for the beautiful results they give, and the added strength and economical use of materials they lend to a project.

Figure 1-1. This archery bow was shaped from an Osage orange blank that had been split out of a green, fresh-cut log, a technique that ensures the wood grain does not run out. Here the steam-bent curve is retained by a single clamp while the wood dries.

A History of Bending Wood

Some type of wood bending has existed at least since the invention of the bow and arrow. For hundreds of years, boat builders have used wood bending to create the ribs that run across the width of boats (**Figure 1-2**), and bentwood bodies replaced hollowed out logs in the construction of stringed musical instruments by the mid-fifteenth century (**Figure 1-3**).

The Origins of Bentwood Furniture

Unlike the origins of some other bentwood forms, the first use of bentwood for furniture is hard to pin down. Some evidence, in the form of tomb paintings and relics, suggests the ancient Egyptians used the process (**Figure 1-4**). In some cases, they simply carved wood into a curved shape or used tree limbs that were already bent, and in other situations actually bent the wood themselves. The mystery continues into the fifth century B.C. in ancient Greece, in the form of the Klismos chair, which could have been constructed using bent members (**Figure 1-5**). No original chairs have survived, so the exact construction technique cannot be determined. Chairs with bentwood backs were made during the Middle Ages and by the eighteenth century, both steam bending and solid-wood laminate bending were well-known techniques.

The first widespread use of bentwood to construct furniture in the Western world was the Windsor chair in early eighteenth-century England. The Windsor chair had a curved back that gained strength from the curved wood connected to the seat (**Figure 1-6**). This was most likely done to save labor and material rather than for aesthetic reasons.

Figure 1-2. Wood bending has been used for hundreds of years to build ribs, planks, and gunwales in boats.

Figure 1-3. This violin, manufactured in 1658 by Jacob Steiner, offers excellent examples of wood bending on the sides, front, and back. Steiner (1617-1683) was among the best known Austrian luthiers. Traditionally, the arched tops and heads of violins and cellos were carved from solid wood. The sides are heat-bent pieces of solid wood, anchored to corner blocks.

Photo courtesy of Barbara [illegible]

Figure 1-4. A cedar chair with the figure of the Egyptian god of eternity, Heh, carved in the back. The original bentwood chair was found in Tutankamun's tomb, and is on display at the Cairo Museum. This reproduction was made in 1976 by Michael Gold of New York City.

Figure 1-5. The Greeks could have used wood bending to construct chairs, like this Klismos. The Klismos is known only from ancient illustrations on pottery—no actual examples have survived.

Figure 1-6. The Windsor chair marked an early and widespread use of bentwood in furniture making. The back/arm piece is a single steam bend. This continuous-arm Windsor was made in 1998 by Michael Dunbar of Portsmouth, New Hampshire.

Bentwood Furniture and the Industrial Revolution

Wood bending for furniture really came into its own during the industrial revolution with the work of Michael Thonet, a German-Austrian furniture maker and industrialist. His elegant and simple designs were enormously popular in the mid-nineteenth century (**Figure 1-7**). Thonet experimented with bending solid wood and laminates, and developed a practical production method for bending using steam along with steel compression straps. By the mid-1800s, manufacturer J. & J. Kohn became Thonet's chief rival, opening several factories internationally, employing an estimated 6,000 people and producing more than 7,000 pieces of furniture daily. The company's growth and the expiration of Thonet's patent for his wood-bending process led to the manufacture of large quantities of bentwood furniture by many manufacturers. The curvilinear shapes of bentwood also lent themselves to the emerging Art Nouveau style (**Figure 1-8**). The use of bentwood became popular for several reasons, including the efficient use of labor and material, the added strength of bentwood, and aesthetics.

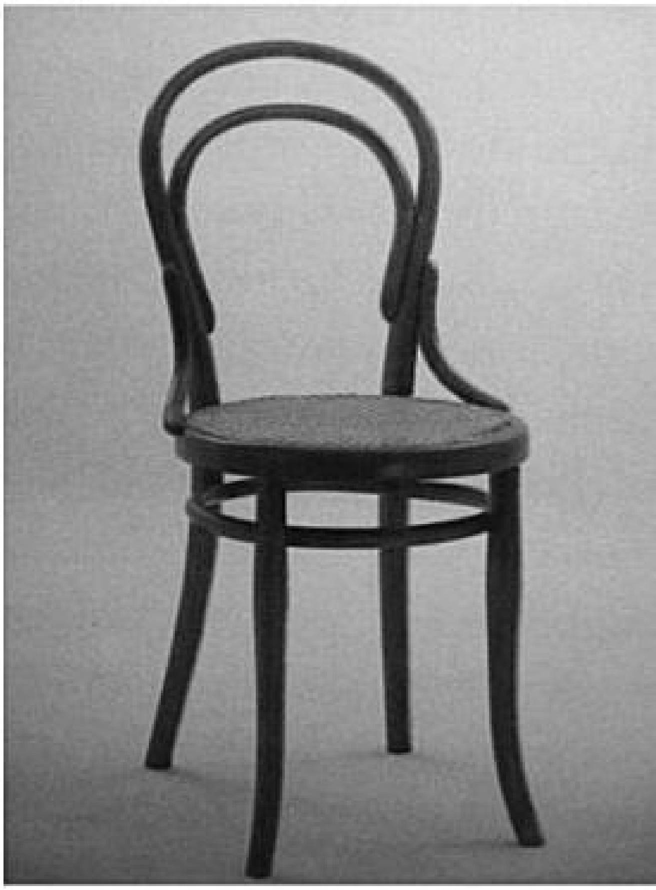


Figure 1-7. Michael Thonet developed simple but elegant curved designs and a steam-bending method. His Model #14 chair—now 150 years old—is his most famous design.

Figure 1-8. The curvilinear shapes of bentwood fit in well with the organic Art Nouveau style.

Plywood

The next revolution in wood bending came with the development of plywood. In 1865, John Mayo first patented an early type of plywood in the United States. Plywood gains tremendous strength and stability from its construction, which features thin layers of wood glued together with the grain pattern of each layer perpendicular to the last. The construction method, called cross-grain lamination, keeps the grain of the wood from expanding and contracting, creating a panel stronger than solid wood. Plywood's potential was not fully realized until the invention of the hydraulic hot press and moisture-resistant synthetic adhesives in the early part of the twentieth century.

By the 1920s and 1930s, Finnish architect Alvar Alto, Hungarian-born architect and furniture designer Marcel Breuer, and others were designing and manufacturing bent-plywood furniture. During World War II, new airplane technology developed by John Northrop of Newark, New Jersey, and Charles and Ray Eames of Los Angeles, California, resulted in many manufacturing advances for the molding and shaping of plywood. After the war, the new technology led to many popular furniture designs by the Eameses and later by many others (**Figure 1-9**). Another advancement was the introduction of the vacuum press, the use of which will be detailed in this book (**Figure 1-10**). The vacuum press allows anyone to create bent-plywood panels with an almost unlimited range of shapes and sizes.

Figure 1-9. Bent-plywood furniture became extremely popular in the 1930s and 1940s. This is a reproduction of an Eames design.

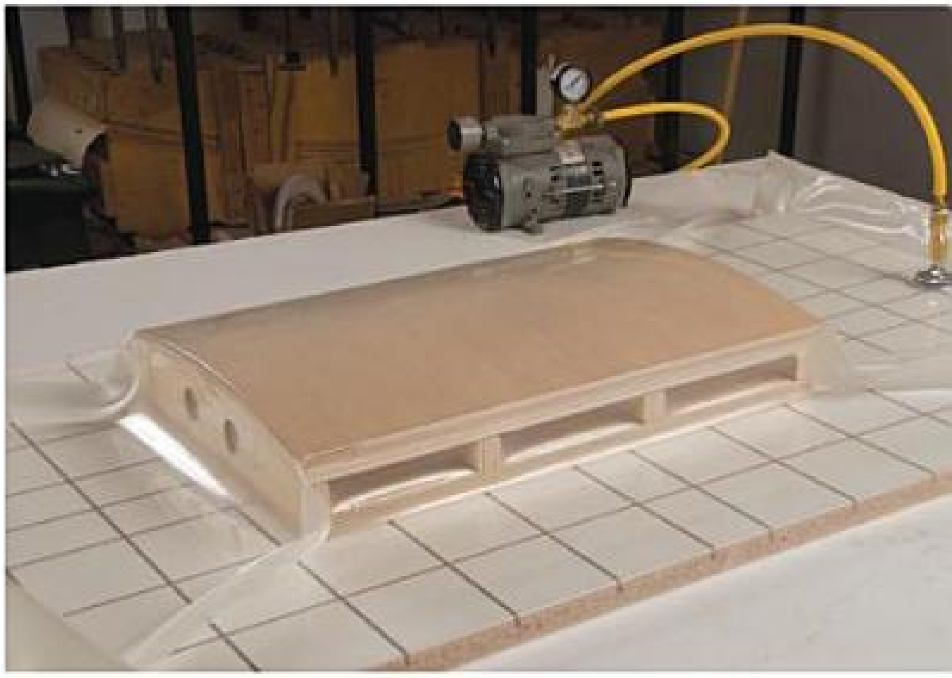


Figure 1-10. The inexpensive vacuum press opened up the possibilities for bending plywood panels in the small workshop.

Bending Wood Today

The availability of the vacuum press at a relatively low cost allowed individuals to create forms that previously only large enterprises with expensive equipment could produce (**Figures 1-11 to 1-24**).

Figure 1-11. Jefferson Shallenberger, of Fort Bragg, California, created *Tendril* in 2003. It features bent laminated legs, and for the writing surface, book-matched light mahogany veneer. The careful workmanship and striking design earned the piece an Award of Excellence from The Furniture Society.
Composition: mahogany, jarrah, redwood burl, holly, silver.
29" (74cm) high by 49" (124cm) wide by 25" (64cm) deep.

Figure 1-12. Kevin Irvin, of Phoenix, Arizona, created *Red Orbitz* in 2004. The retro-styled piece features oval drawer boxes and compound-curved drawer fronts, which were made by bending veneers around a form. Composition: bubinga; 50" (127cm) high by 16" (41cm) wide by 14" (36cm) deep.

Figure 1-13. Matthias Pliessnig, of New Bedford, Massachusetts, made *Shell* in 2003. It's strip laminated on a form, like a canoe. Composition: mahogany, concrete. 27" (69cm) high by 74" (188cm) wide by 16" (41cm) deep.

Figure 1-14. *Serpentine Card Table* (2003), by Richard H. Oedel of Salem, Massachusetts, features curved front and side aprons made by gluing face veneers onto a bent-laminated blank. Composition: mahogany, crotch birch, holly, Gabon ebony; 29" (74cm) high by 36" (91cm) wide by 18" (46cm) deep.

Photos courtesy The Furniture Society, www.furnituresociety.org, from the 2004 Curv-iture exhibition.

Figure 1-15. This Nordic pipe box by Jim Anderson is an example of the simple but elegant piece you can create through wood bending. Composition: black cherry, quilted maple and maple burl. 3½" (9cm) high by 6" (15cm) wide by 22" (56cm) long.

Figure 1-16. *Oseberg Tine* by Jim Anderson is another Nordic-inspired bentwood box. Composition: birdseye maple and maple burl. 6" (15cm) high by 7" (18cm) wide by 16" (41cm) long.

Figure 1-17. Handles constructed for *Dragon Tray* by Jim Anderson are Scandinavian-style dragons. Composition: black cherry and maple burl. 5" (13cm) high by 6½" (16cm) wide by 15½" (38cm) long.

Figure 1-18. Michael Craigdallie, of Nanaimo, British Columbia, Canada, worked *Lotus Box* in 2002. It won the People's Choice Award at the 23rd Annual Box and Container Show in Seattle, Washington. The leaves presented the trickiest challenge, requiring 50 different jigs to form the bent laminations. The legs are cut from solid wood, but the ribs between the leaves are steam bent. The bud spins on a dowel rising from the base, and the leaves fold down to expose shelves. Composition: Quilted western maple, paudauk, maple. 43" (105cm) high by 18" (46cm) wide by 18" (46cm) deep.

Figure 1-19. Mark Koons, of Wheatland, Wyoming, worked *A Simple Chair* Prototype in 2003. The project is not as simple as its name suggests. Koons worked out the design over five years, first experimenting with steam bending but in the end using bent lamination and veneers. It contains 218 pieces and requires 50 clamps to shape the parts around forms. Composition: curly cherry veneer, kangaroo hide seat. 31" (79cm) high by 26" (66cm) wide by 22" (56cm) deep.

Photos courtesy The Furniture Society, www.furnituresociety.org, from the 2004 Curv-iture exhibition.

Figure 1-20. *Spiral Coffee Table* by Jonathan Benson incorporates curves that push the limits of bent panel lamination. Composition: mottled makoré and curly maple. 17" (43cm) high, 36" (91cm)-diameter glass.

Figure 1-21. *Pedestal* by Jonathan Benson features sides made using a two-part form in a veneer press. It's made of pomele sapele veneer, maple burl, and a marble top. 43" (109cm) high by 15" (38cm) wide by 15" (38cm) deep.

Figure 1-22. *Curved Cabinet* by Jonathan Benson features solid wood-bent lamination and bent panel lamination. The differences and similarities in how the wood colors and the curved and straight pieces are used to add interest to the cabinet visually unify the piece. This is the demonstration cabinet shown throughout this book. Composition: walnut and cherry. 52" (132cm) high by 26" (66cm) wide by 19" (48cm) deep.

Figure 1-24. *Constructivist Hall Table* by Jonathan Benson combines simple curves to create a strong sense of motion and energy. Composition: walnut and cherry. 35" (89cm) high by 48" (122cm) long by 15" (38cm) deep.

Figure 1-23. The curvy base of *W Table* by Jonathan Benson pushes the limits of bent panel lamination. It was made using a four-part bending form. Composition: bubinga. 17" (43cm) high by 44" (112cm) wide by 22" (56cm) deep.

CHAPTER 2

Getting Started in Bending Wood

Before you actually start soaking, steaming, or heating wood for your next project **(Figure 2-1)**, it's helpful to have a good understanding of exactly how and why wood bending works and what considerations are most important when you're planning your project. Chapter 2 will give you an overview of the science of wood bending and some information and checklists to use to make sure everything is in place before you begin.

Figure 2-1. Steam and heat soften wood fibers, allowing them to bend. A steam box is simple to construct.

The Principles of Bending Wood

Though the applications and methods for bending wood can seem complex, they are all based on a few fundamental principles. The wood fibers must be able to stretch and compress along the curve, and the proper amount of moisture and heat must be present to keep the wood pliable during bending.

Stretching and Compressing

Bending wood can be a challenging process until you understand just what happens to wood fibers when they are bent. While wood fiber can compress without failing, there is a limit as to how far it can be stretched without cracking or splitting.

Wood bending requires two things to happen simultaneously. The fibers on the outside of a curve need to stretch and the fibers on the inside need to compress **(Figure 2-2)**. The cellular walls of wood compress much more easily than they stretch, which is why the most common failure when bending wood is splitting on the outside of the curve **(Figure 2-3)**.

In some situations, splitting along the outside curve can actually be a significant factor, as illustrated in the following example. A piece of ¾" (20mm)-thick red oak was bent to a 15" (38cm) radius. The original length of the piece was 34½" (87.6cm) **(Figure 2-4)**. After steam bending, the outside surface measured 36⅛" (91.8cm) long, and the inside surface measured 34⅜" (87.3cm) long, a difference of 1¾" (4.5cm). The differences mean the fibers on the outside of the curve had to stretch and slide by each other ¾" (20mm), while the fibers on the inside were compressed 1⅛" (29mm), all without the wood cracking or folding **(Figure 2-5)**. This example is a strong testament to the forces going on inside a piece of wood as it is being bent. Because wood will more easily compress than stretch, a greater amount of change is seen

Figure 2-3. Splitting along the outside of the curve is the most common failure in wood bending because wood fibers compress on the inside of the curve more easily than they stretch on the outside of the curve. Watch for grain that runs out to what will be outside surface of the curve.

Wood-Bending TERMS

Adjustable end blocks. Blocks of wood on both ends of a compression or bending strap that keep end pressure on the wood piece as it bends.

Air-dried. Wood dried without additional heat (as in a kiln). The moisture content of air-dried wood is often higher than that of kiln-dried wood.

Bent lamination. Taking several layers of wood, each of which is thin enough to bend on its own, or with the added moisture of an adhesive, and gluing them together in a curved form.

Compression or bending strap. A metal strap placed on the outside of a curve to keep the wood fibers in compression to help prevent the wood from splitting and cracking.

Grain run-out. Wood grain that travels through the outside surface of the bend and is likely to split at the point where it breaks the surface.

Heating. Bending wood by adding heat, such as with a bending iron.

Kiln-dried. Wood that has been dried in a kiln, usually to about 6% to 9% moisture content.

Lignin. A flexible, glue-like chemical in wood that, when wet, allows wood to bend and, when dry, gives wood rigidity.

Steam bending. Using steam and heat to bend wood, often through the use of a steam box.

The Principles of Bending Wood

All the various methods for bending wood are based on a few fundamental principles:

—Green, fresh-cut wood is supple and easy to bend because it contains a lot of moisture.

—Dry, stiff wood can be made supple for bending by adding both heat and moisture.

—Thin pieces of wood are easy to bend because the fibers on the outside of the curve don't need to stretch around the curve.

—Thick pieces of bent wood can be built up from many thin layers glued together.

—Thick pieces of solid wood can be bent by adding heat and moisture, and by restraining the length so the outside fibers can't stretch and break.

Figure 2-2. A thin piece of wood is flexible and easy to bend without breaking.

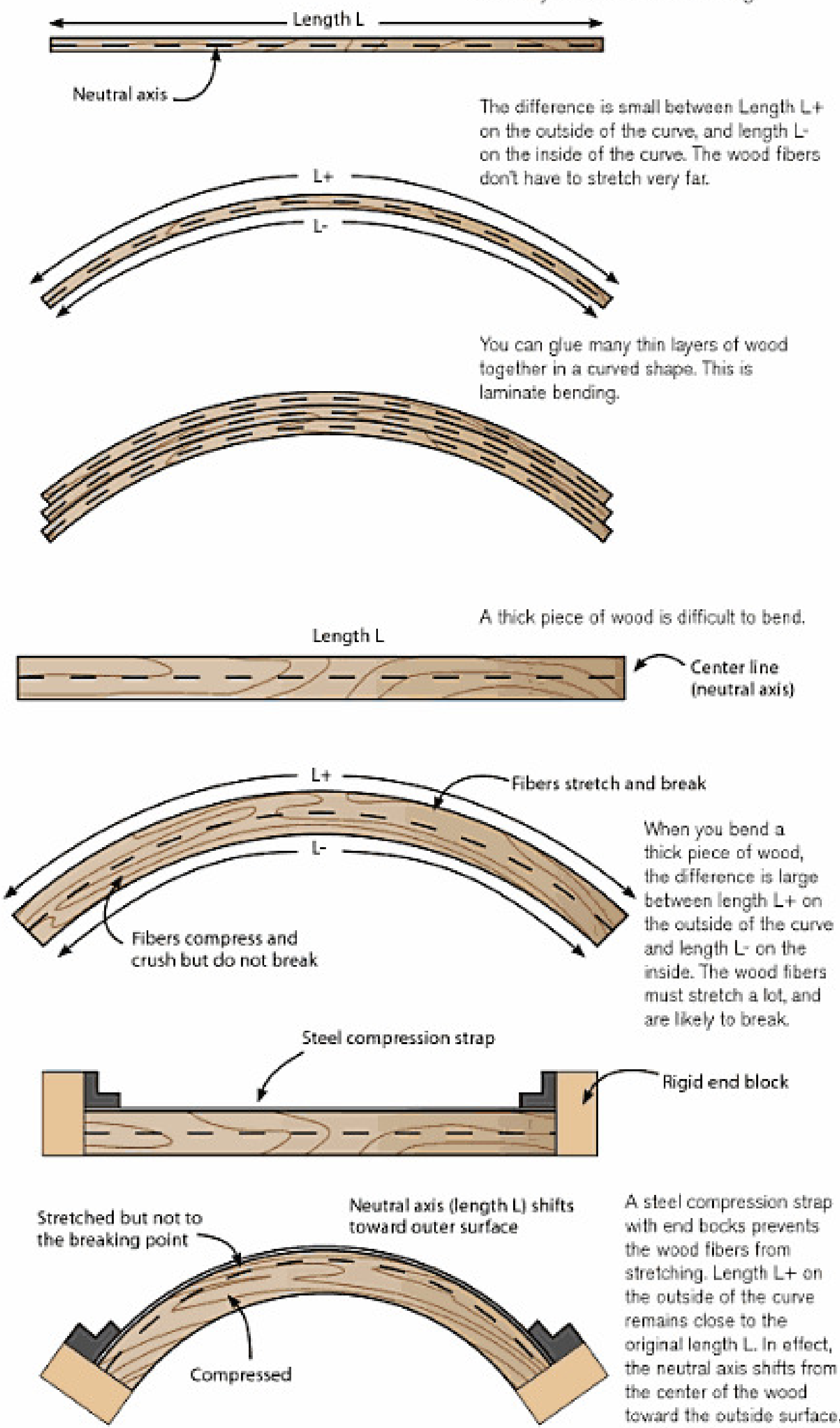
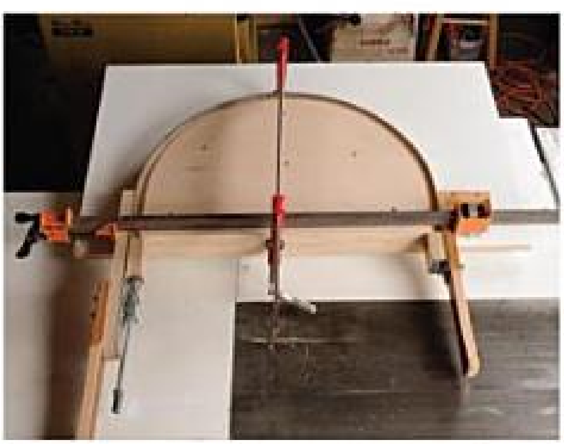


Figure 2-4. The original length of the board was 34½" (38cm). After steam bending, the outside surface measured 36⅛" (91.8cm) long, and the inside surface measured 34⅜" (87.3cm).

Figure 2-5. This piece of ¾" (20mm)-thick red oak was steam-bent to a 15" (38cm) radius. During the bending process, the fibers on the outside of the curve stretched ⅝" (16mm) while the fibers on the inside of the curve compressed 1⅛" (2.9cm).

Figure 2-6. A metal compression strap helps keep the wood fibers in compression to prevent splitting and cracking.

Figure 2-7. Adjustable blocks on either end of the strap exert pressure on the ends of the wood and also help to keep the wood from splitting, cracking, or folding.



on the inside curve. If you were to draw a line at the center of force or where the wood fibers do not move, it would be about two-thirds of the way in from the concave side or one-third of the way in from the outer surface.

To help prevent the wood fibers on the outside of a bend from splitting and cracking, a metal compression or bending strap can be placed on the outside of the curve **(Figure 2-6)**. The strap should be made of a flexible strip of galvanized, stainless, or spring steel. These types of steel will not react with the wood, and won't create stains in the wood that cannot be removed.

In addition to the strap, adjustable blocks on both ends of the strap can be used to exert pressure on the ends of the wood **(Figure 2-7)**. The compression exerted by the end blocks prevent the wood fibers from stretching, which also keeps the fibers from separating on the outside surface of the curve. Remember in the example above how much the outside surface of our board was lengthened and the inside shortened as the wood was bent? When end blocks are placed on either end of the wood, the wood will reach the length between the blocks partway through the bending process. As bending continues, the ends of the curves are forced into the end blocks, creating tremendous inward pressure that forces the fibers together. The controlled pressure is what allows the wood to bend, stretch, and compress, all at the same time, without splitting, cracking, or folding.

Moisture and Lignin

Wood's biological makeup allows it to stretch and compress. You've probably witnessed wood's natural elastic properties because wood must be able to bend as it grows. In some species, branches that grow out from the trunk of a tree spread out and drop down to allow the upper branches more room to grow. The added weight of twigs and leaves at the end of a branch can also cause a branch to bend down, but without breaking. Also, trees can become damaged but not killed by the weight of ice, snow, or other trees that may fall on them. They can be bent over by wind or can grow on a steep hill at an angle **(Figure 2-8)**.

Moisture content plays a key role in wood's ability to bend. To give you an idea of how much water is present in wood, consider that most freshly cut trees (which have nearly the same amount of water as living trees) weigh at least twice their dry weight, and almost all of the weight difference is the amount of water present in the wood. The water keeps lignin, a chemical in wood that acts like flexible glue, pliable. Lignin, in turn, helps wood stretch and compress without tearing. Conversely, when lignin hardens, it adds rigidity to wood.

It's also important to understand moisture content on the microscopic level. Wood, like most other organic materials, grows by cell division. As the cells grow, they accept and transport moisture and nutrients much like a sponge does with water. Long after the tree has died, the wood cells continue to absorb and release moisture in this sponge-like manner, which is why solid wood will continue to expand and contract even after it has been cut, dried, and finished. Wood's exceptional ability to absorb and release moisture is usually a headache for most woodworkers because it means the continual expansion and contraction of wood with seasonal moisture changes. However, the easy moisture exchange aids in bending of wood.

Figure 2-8. You've probably witnessed wood's natural elastic properties. In this photo, the tree has grown at an angle under the weight of wind, snow, and ice.

Understanding that wood absorbs and releases moisture and does so even after it has been cut and dried suggests a variety of ways for us to add moisture to wood, which softens the lignin and makes the bending process easier. Because we also know lignin lends rigidity to wood when it dries, we know we want to allow the wood to dry properly so it better holds its curved shape. Remember, however, that bentwood will usually have a tendency to return to its original shape, so some springback should be expected.

To Bend or Not to Bend a Project?

Now that you know the basics of how wood bends, let's look at what you'll want to consider before starting a project. The first decision you will need to make is whether or not bending is right for your design. Ask yourself the following questions:

Is the shape easier to cut from a solid piece of wood? Cost plays a part here because there will most likely be a lot of waste resulting from cutting a curved shape from a straight piece of wood. The longer the curve and the tighter the radius, the more waste there will be. In most woods, the fibers are running in one direction, so there may be a weak spot where the grain is short.

Does the grain of the wood lend itself to bending? Some figured woods have grain that runs in an irregular pattern, which will tend to split or crack near the outer surface of the bend.

Where will the finished piece be used? Think about the finish you want to use and where the piece will be located. If the piece is to be painted or stained dark and kept inside, several solid pieces of wood may be able to be joined to create the desired shape.

Figure 2-9. Accurate wood bending requires the builder to construct forms and jigs, which can be quite time consuming. This example is a two-part form for bending a stack of thin wood laminations. The straight rails align the two parts of the form while they are being drawn together with clamps.

Figure 2-10. Bentwood always springs back to some extent after it has been removed from the bending form. Steam-bent parts spring back more than laminate bends. It takes experience to learn how to predict the amount of springback, and to factor it into your designs.

Figure 2-11. The *Twister Wall Sculpture* allowed artist Jonathan Benson to have more freedom of design. Much of the visual energy in this piece comes from the curves that seem to spiral out from the center.

Figure 2-12. The bent laminated legs of this table are able to support a tremendous amount of weight. The glass top is ¾" (19mm) thick, nearly 5' (152cm) in diameter, and weighs more than 200 pounds.

How much time and effort will/can you put in? Consider the labor involved when deciding to use the process of bending. It takes a certain amount of time to construct the molds and jigs (**Figure 2-9**), and there is a failure rate with some bending processes. If you construct a laminated piece, you will need to spend a certain amount of time sawing, smoothing, and gluing the laminations and then cleaning up the dried glue and bringing the piece to its final shape.

How will you cope with the springback? Regardless of how wood is bent, there is a tendency for the curve to relax a little over time. This can be dealt with either by securing the ends or by calculating through trial and error how much a particular species of wood at a particular radius might spring back (**Figure 2-10**).

After considering all of these questions, I often decide on bending for the freedom of design it allows, the added strength it provides, and the efficiency gained when bending multiple pieces (**Figures 2-11** and **2-12**).

Figure 2-13. Some green wood can be bent easily by hand, without any additional moisture or heat, but green wood also has the greatest tendency to spring back.

Figure 2-14. Wood can be soaked to add moisture and make it easier to bend.

Figure 2-15. Soaked wood is often bent over a hot iron.

Figure 2-16. Steam boxes create both heat and moisture to get wood ready for bending.

Choosing the Right Method

No matter the setting—whether it's a large industrial operation or a small shop—there are five basic methods for bending wood.

Bending green wood, or bending wood that was recently alive and hasn't dried (**Figure 2-13**).

Bending wood soaked either in warm water or warm water with a mixture of chemicals (**Figure 2-14**).

Using heat, which can relax the wood fibers, to bend the wood (**Figure 2-15**).

Using steam and heat to force moisture back into the wood before bending it (**Figure 2-16**).

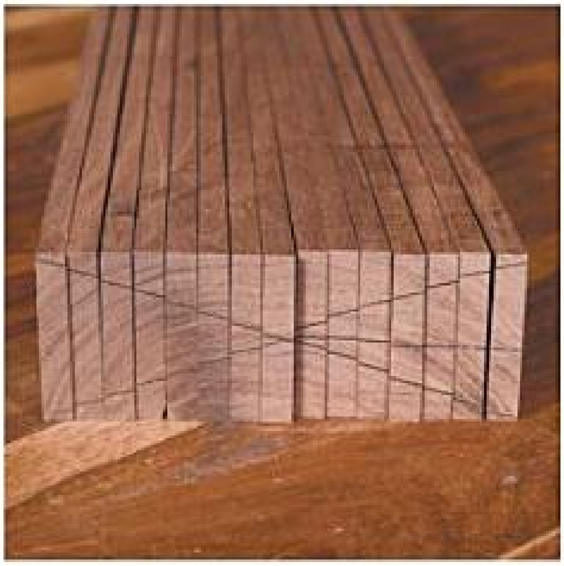


Figure 2-17. In bent laminations, wood is cut into thin layers (left) and then bent in a curved form (right).

Using the bent-lamination technique, which involves taking numerous layers of thin wood, each of which is thin enough to bend on its own or with the added moisture of an adhesive, and gluing them together in a curved form (**Figure 2-17**).

Choosing which method to employ for a particular project usually depends on a number of considerations. The order in which to consider the options may vary from project to project, but it is best to keep them all in mind when making a choice.

Fugure 2-18. Projects made of one layer of thin wood, such as this guitar body, often can be bent with heat and a small amount of moisture.

Type of Wood

The type of material to be used may be the first concern. Ask yourself these questions: What are the properties of the species of wood I plan to use, and how thick should the material be for my project? Will the wood I choose bend to the radius I want in the desired thickness using steam and heat?

For projects such as a guitar body that are made of one layer of thin wood, you may be able to use heat with just a small amount of moisture (**Figure 2-18**). Some species of woods, such as ash and white oak bend more easily than others. Other species of wood may not be able to be steam bent at all and will have to be cut into thin layers and then laminated together in a form.

Wood-Bending Properties

WOOD SPECIES	BENDING PROPERTIES	COMMENTS
Abura	Poor	Not recommended for bending
Afromosia	Fair	Look for small knots
Agba	Fair	
Alder	Fair	Dries out from the steaming process
Ash (American White)	Good	
Ash (European)	Excellent	
Aspen	Fair	
Balsa	Poor	Not recommended for bending
Basswood	Poor	
Beech	Good	Look for pin knots
Berlina	Fair	Look for pin knots
Birch (European)	Good	Many small knots that cause cracks, but bends well if clear
Birch (North American-Yellow)	Excellent	
Blackwood (Austrialian)	Good	
Canarywod (Canarium)	Poor	Not recommended for bending
Camphorwood	Fair	
Cherry (American)	Fair	
Cherry (European)	Good	
Chestnut (American)	Fair	
Chestnut (Horse or European)	Good	
Chenchen	Poor	
Douglas Fir	Fair	
Ebony (Gaboon)	Good	Takes considerable pressure
Elm (American)	Excellent	
Elm (English)	Fair	Defects lead to high failure rate
Elm (Dutch)	Excellent	
Douglas Fir	Fair	
Greenheart	Fair	Tends to split on outer face
Guarea	Fair	
Hemlock	Fair	
Hickory	Excellent	
Hornbeam	Good	Can discolor with steam
Idigbo	Poor	Not recommended for bending
Iroko	Fair	
Jacareuba	Poor	Not recommended for bending
Jarrah	Good	
Kapur	Fair	
Karri	Fair	
Keruing (Gurjun,Yang, Apitong or Eng)	Poor	Not recommended for bending
Krabak (Mersawa, Sabah,Brunei)	Poor	
Larch	Good	
Lignum Vitae	Poor	Not recommended for bending
Lime (European)	Fair	
Luan (Meranti)	Poor	Not recommended for bending
Mahogany (African)	Poor	Not recommended for bending
Mahogany (South American))	Fair	
Makore	Fair	Avoid sapwood
Mansonia	Fair	

WOOD SPECIES	BENDING PROPERTIES	COMMENTS
Maple (Hard)	Good	
Maple (Soft)	Poor	
Muhimbi	Fair	
Huhuhu	Fair	
Muninga	Fair	
Oak (European)	Excellent	Will crack if dried too quickly
Oak (Red)	Good	
Oak (White)	Excellent	
Obeche	Fair	
Odoko	Poor	Not recommended for bending
Ogea	Poor	Not recommended for bending
Okan	Poor	Not recommended for bending
Okwen	Poor	Not recommended for bending
Olive (East African)	Fair	
Opepe	Poor	Not recommended for bending
Pine (all types tested)	Poor	Not recommended for bending
Poplar	Poor	Not recommended for bending
Pterygota (Ware, Awari)	Poor	Not recommended for bending
Purpleheart	Fair	
Rosewood (East Indian)	Poor	
Rosewood (Hounuras)	Poor	
Rosewood (Madagascar)	Good	
Sapola	Poor	
Spanish Cedar	Fair	
Spruce	Poor	
Storculia (Brown)	Fair	
Sterculia (Yellow)	Poor	
Sycamore	Excellent	Watch for defects, and this wood tends to have many
Teak	Fair	
Walnut (European, French, English)	Excellent	
Walunt (American, Black)	Good	
Western Red Cedar	Poor	
Willow	Good	Bends very well green
Yew	Fair	

Note: The figures in the table are for the steam bending of kiln-dried wood approximately 1" (2.5cm) thick after about 40 minutes in the steam box. The ratings are:

- Excellent–recommended industry standard that can be bent to at least a minimum radius of 3" (7.5cm).
- Good–can be reliably bent to a radius of 3" (7.5cm) to 15" (38cm).
- Fair–can usually be bent to a radius of 15" (38cm) to 24" (61cm), but extra care should taken to avoid defects that could cause the piece to split or crack. (You may want to consider bent laminations.)
- Poor–not recommended for steam bending, but could be made into curved shapes using bent laminations.

Most of the woods in the table can be made into smaller radii using the technique of bent lamination.

Figure 2-19. Splitting your own wood for bending is the best way to get a piece with the grain following the surface throughout. This is Osage-orange for bow-making.

Figure 2-20 Wood with grain relatively parallel to the surface of the board is better for bending than this walnut, which has grain runout.

Figure 2-21. The wide grain in this piece of hickory (above) will make it easier to bend than this tight-grained piece of butternut.

Figure 2-22. Because mahogany lacks a strong grain pattern, it does not bend well

Grain

When talking about wood for bending, we must consider grain. Wood to be bent must have the grain as parallel to the surface as possible without running out to the surface. If the grain starts to cut across the thickness of the curve, it will tend to split where the grain ends, or runs out on the outside of the curve (see **Figure 5-34** on page 97).

The ideal piece of wood for bending would be cut from the log by splitting it off just like a piece of firewood (**Figure 2-19**). That way the grain would follow the surface of the wood throughout. Wood cut using this method is hard to find unless you cut it yourself, so just try to find wood with the grain running as parallel to the surface as possible.

Wood with annual rings that are parallel or perpendicular to the surface tends to bend more successfully than wood with rings that vary in their orientation to the surfaces from one end of the board to the other (**Figure 2-20**). Wood with annual rings that are farther apart will bend more easily than wood with a close pattern of annual rings (**Figure 2-21**).

Tropical woods generally will not bend well. Moreover, tropical woods without a strong pattern of annual rings, such as mahogany, do not bend well at all (**Figure 2-22**). They tend to just fold and crumple under pressure.

Figure 2-23. Avoid defects, such as cracks and knots, when choosing wood for bending.

Figure 2-24. Figured wood, such as this elm burl, is not a good choice for bending, because the grain pattern makes the wood more likely to rip, tear, or fail.

Figure 2-25 This piece of red oak was overcooked, which made it too soft to bend properly. You can see how it folded on the inside of the curve and also ruptured the outside.

Defects

Even the best bending woods should be free from cracks, knots, checks, and other defects, particularly on the outside of the curve (**Figure 2-23**). Defects create the potential for the wood to break or split during bending. For the same reason, figured woods or woods with an interlocking grain pattern are difficult to bend, as there are many places for the grain to rip, tear, or fail (**Figure 2-24**). These principles apply to almost every type of bending process including heating, steam bending, and bent lamination.

Because the fibers on the inside of the bend are compressed together during bending, they are less vulnerable to splitting. If necessary, small defects in the wood can sometimes be placed on the inside of the curve without causing a problem. The most common failure on the inside of a bent piece of wood is folding (**Figure 2-25**). This can occur when the species of wood chosen is too soft to bend, or when the wood is overheated or the inside unsupported. Woods commonly too soft to bend around a tight radius include cherry, mahogany, and some types of walnut as well as the tropical woods mentioned earlier. (Consult the "Wood-Bending Properties" table on page 24 for a listing of which species of wood can be bent most successfully.) If you must put a defect on the outside of a bend, a compression strap can help hold down the defect to some degree.

Moisture Content

Is the wood green, air-dried, or kiln-dried? Green wood is often difficult to find, unless you can harvest it yourself, and tends to distort as it dries. Green wood also has much more of a tendency to spring back to its original shape than wood that has been dried first and then remoistened.

When wood is air dried or kiln dried, the lignin dries out and hardens, causing the wood to lose its elasticity. This effect is why some of the bending techniques involve spraying water, soaking wood in water, or using steam—to add moisture to dried wood. Remember that after the lignin cools and dries, it again hardens, helping to maintain the shape of the curve.

Air-dried wood will bend more easily than kiln-dried wood because the kilndrying process tends to break down the lignin. (See the "Wood-Bending Properties" table on page 24.) The moisture content of kiln-dried wood is usually brought down to about 6% to 9%. The moisture content of air-dried wood may be slightly higher. Both types of wood have enough moisture present in the lignin for the bending of thin woods into medium to large radii. For thicker woods, increasing amounts of moisture and heat need to be added to soften the lignin and help return it to a more natural, elastic state.

Figure 2-26. Plywood can be an inexpensive and effective material for building both forms and bent panels. The top piece, 3/8" (10mm) bending plywood, has a different layer structure than the other three panels.

Materials Other Than Solid Wood

In addition to wood, some other materials can work well for your project, especially if you are looking for something cost-effective and resistant to movement. Composite materials, such as plywood and medium-density fiberboard (MDF), that are ⅛" (3mm) thick will bend around a medium to large radius in most cases. The materials listed here are some of the most common types:

Plywood with or without surface veneer. Plywood ⅛" (3mm) thick and made of poplar **(Figure 2-26)** or lauan with no surface veneer can be much cheaper than veneer-faced plywood and can be used for the core of a panel and then faced on the outer layer with veneer. The pre-faced plywood (with veneer applied to one face) can also be used for the outer surface to create beautiful uniform curved panels. You can find ⅛" (3mm) plywood at many lumberyards and home improvement stores.

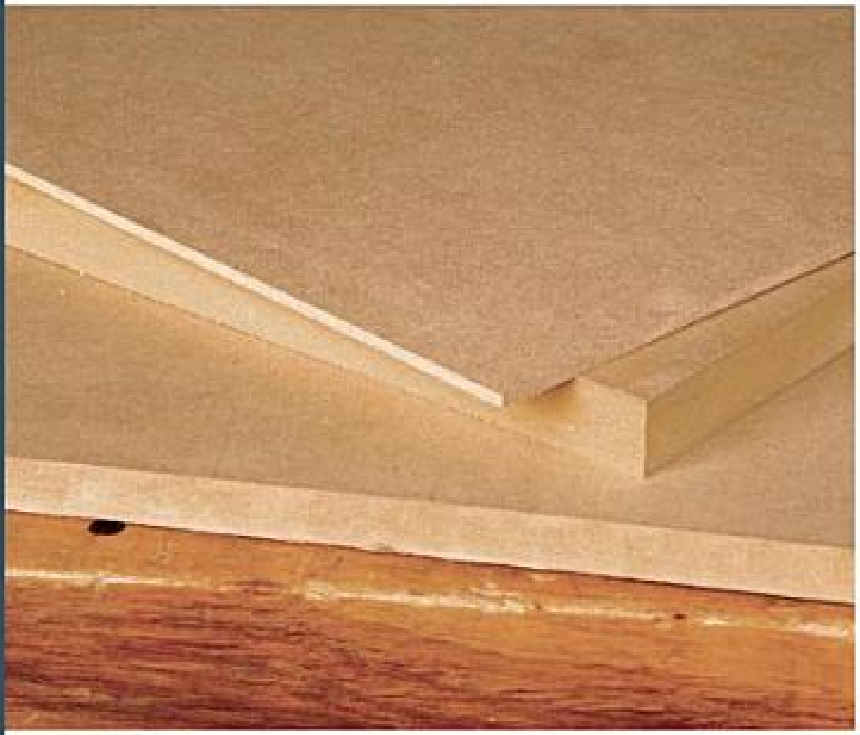


Figure 2-27. Medium-density fiberboard, while good at mimicking wood when used with veneer, can make large forms heavy.

MDF. MDF is also available in ⅛" (3mm) thickness, but is sometimes hard to find. It is usually available at plywood distributors or lumberyards that cater to cabinet shops. MDF has a much smoother surface for gluing than plywood, which means panels that are made with MDF can closely resemble the look and feel of solid wood (**Figure 2-27**). However, MDF will not bend as tightly as plywood and is much heavier than plywood. For panels with a medium to large radius, I often use ⅛" (3mm) MDF for the outside layers and some other lighter materials to construct the inside layers.

Marine plywood. Waterproof bent panels can be created using ⅛" (3mm) marine plywood laminated together with marine epoxy. While ⅛" (3mm) material does bend easily, it takes quite a few layers to build up a thick panel. Marine plywood is available from plywood dealers and lumberyards that cater to the boatbuilding and cabinet trades.

Bending plywood. Thicker plywood intended for bending is known as bender board or bending plywood. This material is usually made of lauan and consists of two thick outer layers with the grain traveling in one direction and one thin inner layer with the grain traveling in the opposite direction (**Figure 2-28**). Bending plywood bends easily across the grain of the outer layers. It bends easily in part because lauan has an open grain structure, which allows wood fibers on the outside of the radius to separate and wood fibers on the inside of the radius to easily compress. The open grain structure of bending plywood gives it a rough surface, however, so it usually needs a cross-band layer of veneer under the surface veneer to prevent irregularities in the surface from telegraphing through the face veneer.

Sold as 4'-by-8' (120cm-by-240cm) sheets, bending plywood can be bent across the width of a panel. Sold as 8'-by-4' (240cm-by-120cm) sheets (sometimes referred to as barrels), bending plywood can be bent along the length of a panel. It also comes in a variety of thicknesses. Thick sheets are excellent for building up a panel quickly. Bending plywood is usually only available at plywood suppliers and lumberyards that cater to cabinet shops.

Figure 2-28. Bending plywood comes in a variety of thicknesses and is specially made for bending, which makes it great for facing forms and for using as a core for veneered bent panels.

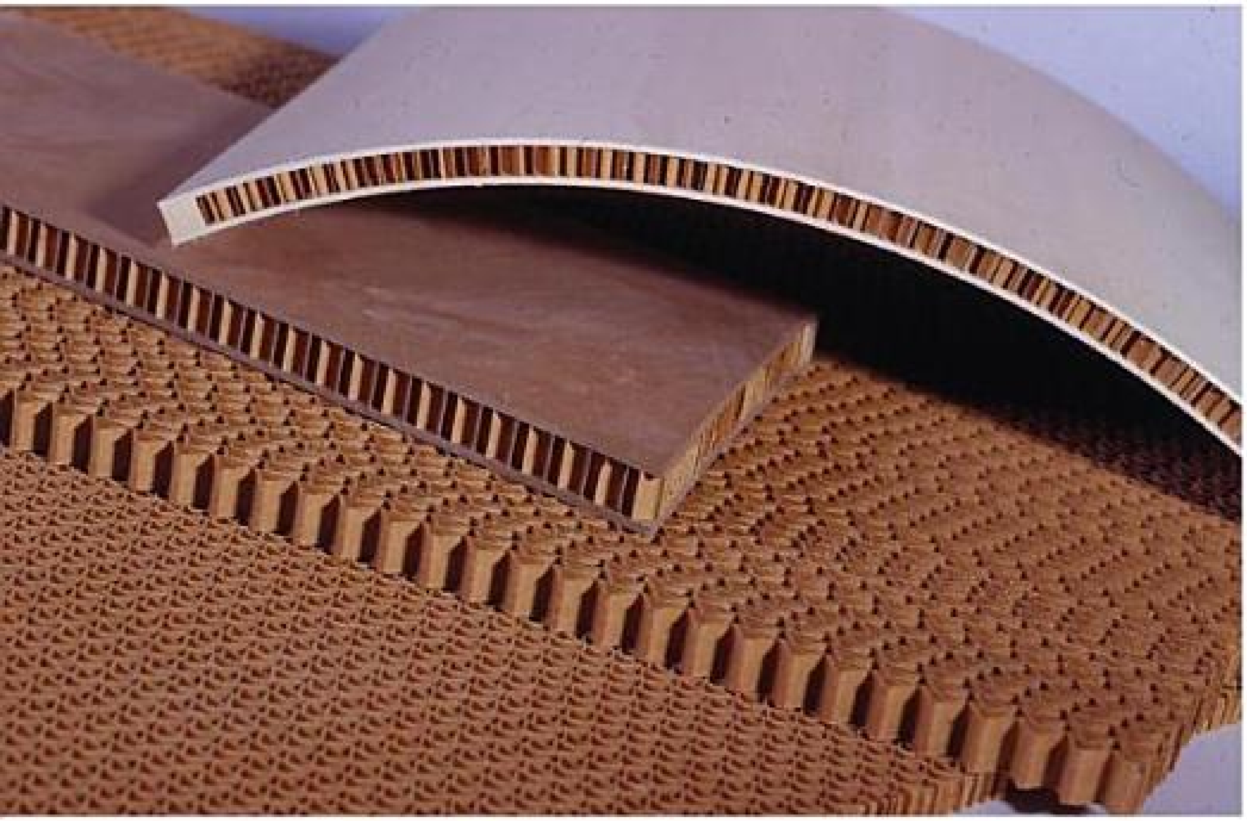


Figure 2-29. The strength and light weight of resin-impregnated honeycombed sheets make them ideal for form building. Some can be veneered to make furniture panels.

Resin-impregnated honeycombed sheets. Another choice for bendable substrate sheets is resin-impregnated honeycombed sheets. The core of this material consists of a network of resin-impregnated paper that is arranged in a honeycombed pattern (**Figure 2-29**). It is available covered with veneer in flat sheets or it can be obtained un-skinned for bending applications. (See the "Resources" on page 179 for more information.) This material is very lightweight yet extremely strong.

Manufactured kerf-cut sheet goods. One type is called Kerfcore. It's made of strips of MDF laid side by side with a gap in between each strip. The MDF strips are covered with thick paper on both sides to create a rigid panel (**Figure 2-30**). When the material is ready for use, one side is usually covered with veneer first. Then, the paper on the other side is cut using a special roller, which allows the panel to easily bend. Kerf-cut MDF is also available in various thicknesses.

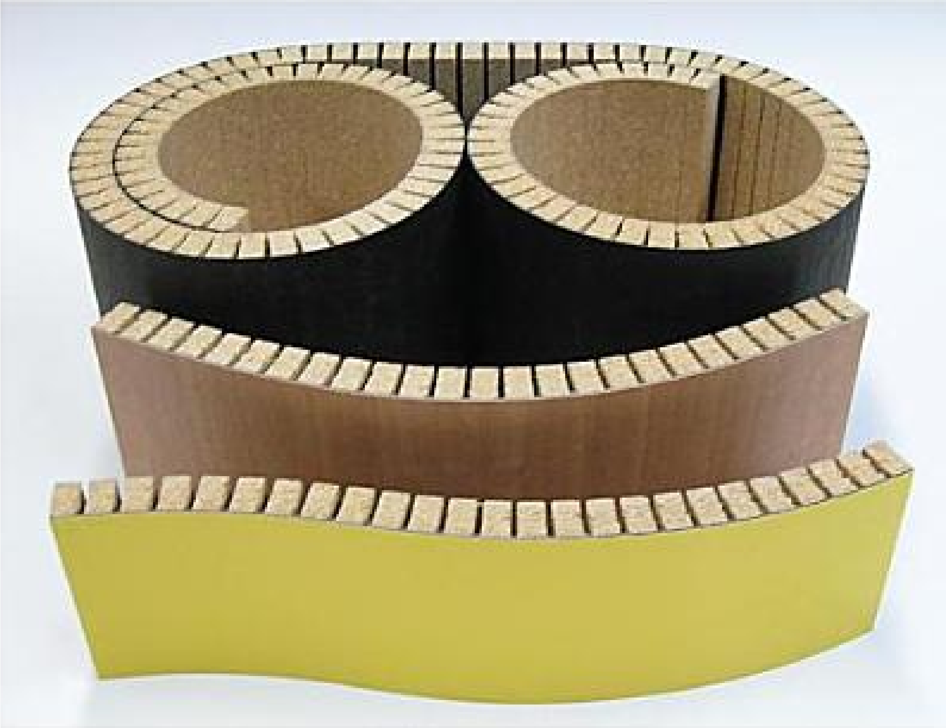


Figure 2-30. Kerfcore doesn't usually require a complex form to bend it. If it is faced with finished veneer in the shop, it can be easily installed at the job site.

Figure 2-31. Light-colored laminations will often show the glue lines between the layers. Consider this aspect of the piece as you are planning your project.

Figure 2-32. Dark-colored laminations cut from the same board and ordered sequentially can nearly hide glue lines.

Final Look

Consider the visual aspects of your project and, specifically, what the edge of the curve is going to look like. If you are constructing a laminated curve using a light-colored wood, there may be glue lines visible on the edge of the piece between each layer (**Figure 2-31**). If you are using a dark-colored wood and you cut the laminations from the same board and then glue them back together in sequential order, you may be able to hide the glue lines altogether (**Figure 2-32**).

Strength and Springback

Strength is another consideration. A laminated curve can be much stronger than the same shape cut from one piece of solid stock, because there is so much glue surface between all of the layers (**Figure 2-33**). The glue could fail, however, if the finished piece is to be used outside. Springback is much less with a laminated piece of wood glued with an adhesive that dries very hard than it is with a steam-bent curve.

Figure 2-33. A laminated curve can be much stronger than the same shape cut from one piece of solid stock.

Figure 2-34.
Using veneer glued to a core of inexpensive wood, such as plywood or medium-density fiberboard, can be a cost-effective way to make wood bending projects. This bent furniture part has cherry veneer on both faces, then ⅛" (3mm) bending plywood sandwiching a ⅜" (10mm) bending plywood core.

Labor

Think about the labor involved. It may be quicker to cut and glue all of the laminations for one bent piece than to construct a steam box and bending apparatus, determine all of the variables mentioned in Chapter 5, and then make the bend. If you are doing multiples, it may be quicker to steam bend each piece.

Cost

Finally, consider your budget. Cutting laminates and smoothing each face before gluing them back together in a form usually results in at least 50% waste. For wider panels, you may be able to use a veneered surface over inexpensive wood (**Figure 2-34**). For details on the technique, see Chapter 7, "Bent Panels," on page 135. Other processes described in this book, such as the use of a vacuum press, the various ways to soften wood, and the use of a microwave oven, push the boundaries of wood bending even further. Having knowledge of these techniques will allow you to construct a variety of curves for many situations. The knowledge will also help you to come up new ways to express ideas and complement wood's inherent beauty.

CHAPTER 3

Bending Green Wood

One early application for bending wood still in use today is the bending of green sticks to construct objects such as furniture, including the chair detailed in this chapter. I have found this is indeed an excellent use for bent green wood. We're starting with this method because it is one of the simplest ways to make a bentwood project.

Figure 3-1.
Bending green wood to construct furniture is an early application still in use today. Here I'm bending the arms of a green branch chair.

Figure 3-2.
Willow stands, such as this one, can be reliable and consistent sources of wood for bending.

Working with Green Wood

Green wood is either freshly sawn or has not undergone any formal drying process. It retains moisture and the wood's natural resins, which can make it easier to bend than wood that has been thoroughly dried. In some cases, freshly sawn green wood can be bent without any pre-treatment. For bending, green wood offers some real advantages, including ease in bending and a rustic appearance.

Wood-Bending TERMS

Felling lumber. Cutting down a live tree to harvest the lumber.

Pre-bend, pre-bending. To bend a stick in a thick area or in an area where the radius will be small before bending the entire stick to create a uniform overall bend.

Riving wood. Cutting or splitting wood from the length of a log, preferably starting at a natural crack.

Rustic-style. An unrefined style of furniture that often incorporates sticks and rough-cut lumber.

Seasoned wood. Wood that has been air-dried to a moisture content of less than 12%.

Choosing the Wood

Various species can be used to make the curved members of projects, but some of the most common species include alder, birch, beech, hickory, and willow. Willow may have the best qualities of all because it bends easily, stays in place, and the bark usually doesn't come off when the wood dries. It can also be a reliable source of material—a good stand of willows near a creek or river will yield new saplings year after year (**Figure 3-2**).

Often, both saplings and branches are suitable for bending (**Figure 3-3**). The saplings work best because they are relatively straight and are easy to prepare, having few offshoots and leaves. Use saplings and small branches to construct the curved components of projects, such as the chair in this chapter, and use thicker branches to make up the support structure.

If you are taking the trouble to cut live branches and saplings, it makes sense to use them right away, before they have a chance to dry out. The sticks can be wrapped in plastic and stored for a while, but they can continue to dry and mildew can be a problem.

Figure 3-3. Saplings and branches can make suitable bending material.

Making a Green-Wood Chair

The chair project shown on the next page is a good exercise in bending willow and a testament to the great bending properties of this wood. For my chair, I cut small willow and Osage-orange saplings in the late summer and used them right away. They were about 1" (2.5cm) in diameter at their thickest. The structural members were cut from limbs of willow and Osage-orange and were slightly more than 1" (2.5cm) in diameter (**Figure 3-4**).

This type of furniture is referred to as rustic-style furniture, so exposed nails, screws, and other hardware are acceptable for joining the individual pieces. Larger pieces can be joined using mortise-and-tenon joints cut by hand, a drill, or a commercially available tenon cutter. Nails or leather straps also work well for joining the wood together.

With rustic furniture, there are often no drawings or set plans. The shapes and sizes of the wood at hand and the maker's eye often will be determining factors when creating a design. A few basics are important, however, such as the height, width, and depth of the seat and the height of the arms. (For guidelines, see "Common Chair Measurements," page 36.)

The project detailed here is a child's chair, so it will be a bit smaller than an adult-size chair. The seat will be about 12" (30cm) high, 15" (38cm) wide, and 15" (38cm) deep.

Common Chair Measurements

Chair Type	Seat Width	Seat Depth	Seat Height	Back Height
Barstool	17" (43cm)	17" (43cm)	30" (76cm)	42" (107cm)
Child's	18" (46cm)	15" (38cm)	12" (30cm)	40" (102cm)
Dining, Side	19" (48cm)	19" (48cm)	18" (46cm)	36" (91cm)
Dining, Arm	24" (61cm)	18" (46cm)	18" (46cm)	36" (91cm)
Easy	25" (64cm)	26" (66cm)	17" (43cm)	31" (79cm)
Kitchen	19" (48cm)	19" (48cm)	19" (48cm)	34" (86cm)
Kitchen Stool	12" (30cm)	12" (30cm)	27" (69cm)	
Rocker	20" (51cm)	26" (66cm)	16" (41cm)	42" (107cm)
Upholstered	30" (76cm)	26" (66cm)	16" (41cm)	40" (102cm)

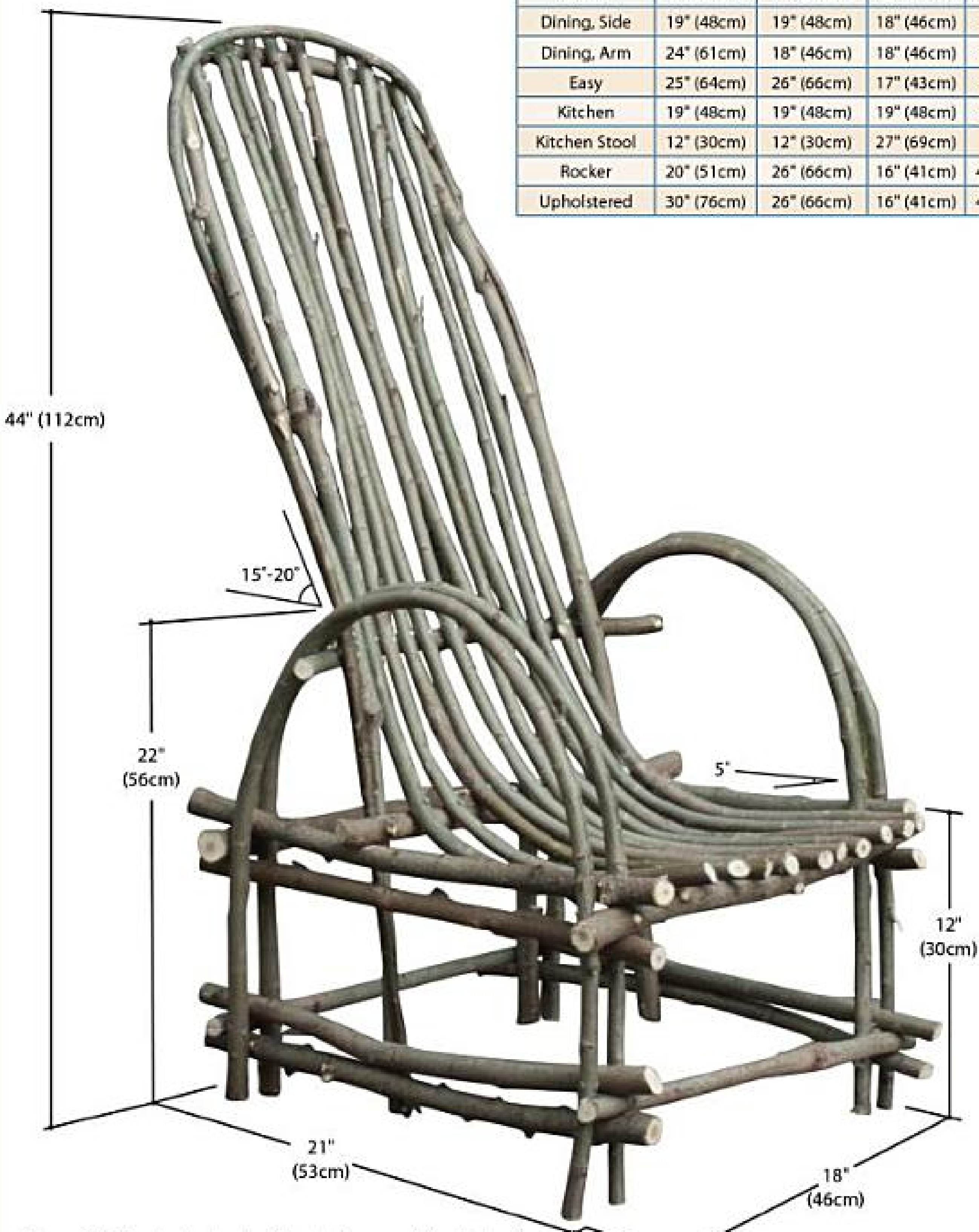


Figure 3-4. The structural parts of the chair were cut from limbs of willow and Osage-orange just over an inch (2.5cm) in diameter.

DEMONSTRATION PROJECT: Making the Rustic Chair

In addition to supporting the seat, the frames for this chair hold the bent elements in tension, which adds much strength to the overall structure of the chair. You will need to pre-bend the thick end of each member over the edge of a bench or with your hands. Otherwise, the pieces will tend to bend more where they are thinner and less where they are thickest, resulting in uneven curves. The members are attached using galvanized nails with heads. Some joints could be wrapped with leather to add strength and detail.

Step 1. Make a framework of straight material roughly to the dimensions shown. A branch with a slight curve for the front seat support will help to make the seat more comfortable. I made two frames of the same size to add more strength.

Step 2. Predrill each hole before nailing to avoid splitting the wood. Always try to orient the pieces to be nailed against the bench so the force of the hammer is directly transferred through the nail to the bench.

Step 3. After the two frames are completed, bend the arms, which will go inside the lower frame on each side, and nail them in place, leaving the wood a little long on the ends.

Step 4. Bend and nail the outside arm members in place. This is where pre-bending is essential for matching the curve of two pieces that are so close to each other.

Step 5. Apply the upper seat frame. You may want to angle the seat frame back a little, about 5° or 10°, to make the chair comfortable. Cut the ends of the branches off to create the feet and set the height of the chair.

Step 6. Nail a cross brace between the arms to support the back. I bent this member so the back would be curved, which helps make the chair more comfortable. Remember, always nail so that the force of the hammer is directly transferred through the nail to the bench. This allows each nail to be driven in hard and prevents the force of hammering from loosening the rest of the joints.

Step 7. The back is constructed of two long branches. They can be wired together with the thick end of one branch attached to the thin end of the other. The wire will help the two pieces to bend uniformly and will help keep everything in place as you finish the chair. The wire will be removed when the chair is complete. The structure of the chair should then keep the two long branches in place.

Step 8. The loop for the back is tilted back slightly and nailed to the inside of the frame and to the cross brace. Bend the loop of the back around, and secure it with a stick across the rear of the seat frame. Nail the loop to the arm, the seat frame, and the lower frame. Then, remove the wire.

Step 9. The framework of the chair is now complete.

Step 10. Finally, the seat and back will need to be filled in. Pre-bend the first piece to the shape you want in order to create a comfortable seat and back. Then, pass it between the top two pieces that make up the back.

Step 11. Drill and nail the vertical piece to the front rail. Shape the seat by bending the piece as shown and then predrilling and nailing it to the back rails and the front rail.

Step 12. Complete the profile of the seat and the lower part of the back by attaching the vertical piece to the cross brace. Repeat the process for the rest of the vertical members to complete the seat and the back.

Step 13. The pieces can be spaced as far apart or close together as you want depending on your design and how much wood you have. These were spaced about ¾" (20mm) apart.


PATTERN

CHAPTER 4

Materials and Techniques for Bending Forms

In Chapter 4, we'll discuss some of the best pattern-making techniques, discuss different bending forms you'll need, and review some adhesives that will help you along the way. A pattern helps you construct the form in which the curve will be bent and can act as a pattern for aligning the pieces of the project at various times during construction **(Figure 4-1)**. Begin by drawing your pattern, using any of a myriad of drawing tools. The method you ultimately use to construct your form will in part be determined by what type of curve is required for your project. For some, one-part forms, or one-part forms with vacuum bag will work well. For others, a two-part form, with or without vacuum assistance, will be the perfect method of bending wood for your project. There are a variety of construction techniques you can utilize to build your forms. In turn, the type of curve you're developing and your form will help determine what type of adhesive you utilize for your project. Though you'll find the tools and supplies you need for each wood-bending project are different, most projects have common elements. Tools and supplies for pattern making, form building, and gluing should be on your list for almost every project.

Figure 4-1. Basic tools and supplies for wood bending can include a plywood form, a screw gun, and a ruler.

Pattern Making

An accurate full-size drawing, or pattern, is extremely important when making a project containing any type of curve. A pattern helps you construct the form in which the curve will be bent and can act as a pattern for aligning the pieces of the project at various times during construction. Once you have established the method of bending you plan to use, you will also need to determine the amount of springback to expect and account for that in the drawing, unless the bend will be secured at the ends.

Figure 4-2. Trammel points, usually two metal points attached to a piece of wood, make it easy to draw large circles and arcs.

Drawing Tools

Many items, whether they are made specifically for drawing or not, can be useful for drawing curves. In many cases, a compass, a set of trammel points, or even a can or bucket can create an arc or a circle (**Figure 4-2**). For more organic shapes, you may want to try a plastic or metal French curve, a flexible ruler, or various plastic patterns (**Figure 4-3**). Even a washer can make a good guide when following an existing curve (**Figure 4-4**).

Figure 4-3. Flexible tubing, a French curve, a compass, and a pencil are handy to have in your toolbox

Your Drawing Toolbox

Pencil or pen
Compass
Trammel points
Can or bucket
French curve
Flexible ruler
Other flexible plastic patterns
Washer

Figure 4-4. A washer can easily follow an existing curve at a set distance from it.

Wood-Bending TERMS

Blanket. A wide, flexible pad that evens the pressure and spans the distance between the ribs of a bending form to make a smooth surface for a panel to rest on.

Caul. A piece of rigid material used to help clamps and forms apply even pressure to wood laminations.

Compass curve. A curve that is part of circle and could be made using a compass or can be traced from a circular object.

Delamination. The separation of the layers within a plywood panel or glued-up lamination.

Guide strips. Strips that keep both the form and the laminates from sliding around.

Inside form. A bending form used inside a vacuum bag.

Inside technique. A technique using a vacuum press in which both the wood and the form are placed inside the vacuum bag.

Laminations or laminates. Layers of wood that, when placed together with glue in between them, make up a curved shape called a bent lamination.

Manufactured kerf-cut sheet goods. A manufactured sheet material with a series of cuts along its length. The cuts allow the material to flex across the width.

Medium-density fiberboard (MDF). A composite sheet material made from wood dust and glue.

One-part ribbed form. A one-part form made of evenly spaced ribs that can be used inside a vacuum bag to form laminated bent panels.

One-part solid form. A block of wood with one curved side for the bending wood to bend around. One-part solid forms are made of layers of wood.

Open time, or working time. The time you have from applying the glue until it starts to stick. Also called working time.

Organic curve. A variable or undulating curve that cannot be drawn using a compass. Organic curves resemble those found in nature.

Outside technique. A technique using a vacuum press in which the wood is placed inside the vacuum bag but the form remains outside.

Plywood. A composite material made of an odd number of layers that alternate in grain direction to resist wood movement.

Polyvinyl acetate (PVA) glues. Water-soluble glues commonly used for woodworking projects.

Resin-impregnated honeycombed sheets. A material with a core of networked resin-impregnated paper that is arranged in a honeycombed pattern.

Ribbed form. A ribbed form constructed of individual ribs spaced between 2" (5cm) to 6" (15cm) apart. This lightens up the form and makes it ideal for making bent panels. Ribbed forms can be made of one or two parts.

Solid form. A form used for solid-wood laminations, steam bending, and some narrow panels. There are two types of solid forms: one-part and two-part.

Symmetrical design. A design whose sides are mirror images of one another.

Thermoplastic adhesives. Adhesives that dry by evaporation. Can soften when temperature increases and tend to creep under load. When exposed to moisture, the bond is not durable.

Thermosetting adhesives. Adhesives that set as the result of a chemical reaction that occurs when two parts are combined, when water is added, or when heat is applied, to create a rigid compound. Thermosetting adhesives are usually infusible, insoluble, and show good resistance to creep. They are used for heavy loads and severe conditions.

Two-part ribbed form. The same as one-part forms, except with male and female sides. This type of form can used in a veneer press or clamped with thick cauls to distribute the pressure evenly when a vacuum press is not available.

Two-part solid form. Two-part solid forms are the same as one-part forms, except there are male and a female sides.

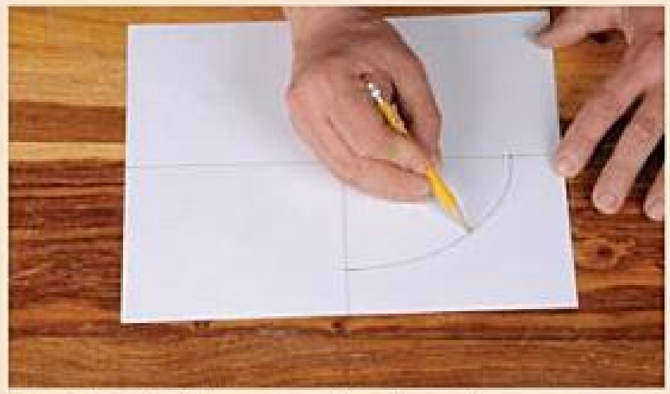
Vacuum press. A press that derives its pressure from the atmosphere around it after all of the air is removed from the vacuum bag.

Veneer press. A screw press that consists of several coarse-threaded clamping screws mounted in a stout wood or steel frame that is tightened down over the work. A veneer press is used in conjunction with a curved form and cauls tailored to the work.

STEP-BY-STEP: Drawing a Symmetrical Curve

Symmetrical curves are common in wood-bending projects. The following method is an efficient and accurate way to produce symmetrical patterns. The pattern shown in the demonstration is the oval shape of a Shaker box.

Step 1. With paper aligned lengthwise in a landscape orientation, draw one vertical and one horizontal line that intersect at the center of the page.

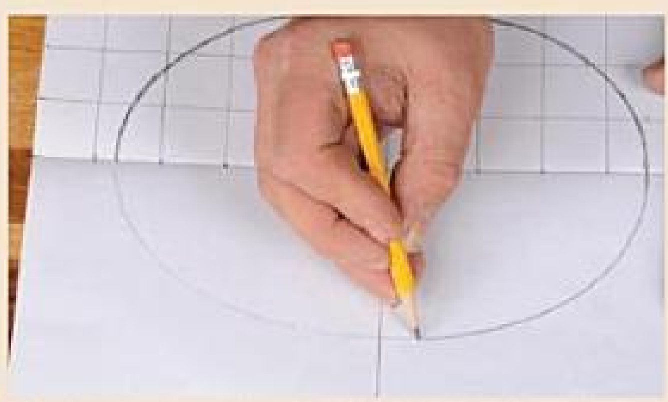


Step 2. Freehand draw one quarter of the oval in one corner of the cross.

Step 3. Next, lay out a gridwork of 1" (2.5cm) squares on the top half of the page. Use the grid as a reference to complete the drawing of the top half of the oval.

Step 4. With a soft pencil, darken the top half of the oval. Fold the paper over lengthwise right along the centerline.

Step 5. Turn the folded paper over so the arc is visible through the paper. Draw over the line from the back of the paper, pressing down hard. This will transfer some of the graphite from the top half of the oval to the bottom half of the paper, completing the shape, much like using carbon paper.



Step 6. Unfold the paper, and sketch in the lower half of the arc to make it darker.

Methods for Drawing Curves

There are several ways to draw an accurate curve. For arcs of circles, often called compass curves, you can use a compass, a set of trammel points, or a can or bucket to create the correct size. For undulating or organic shapes, use any tools that work for that shape and draw some of it freehand.

I often create a freehand curve by sketching and refining the line. If the curved line looks good to the human eye, the finished curve will appear right to the human eye, as well. The form used to bend the wood can be further refined during construction. The goal should be to create an eye-pleasing design.

If the curve is symmetrical—that is, if you were to draw a line through the design's center, it would be the same on both sides—draw one side of the curve and reproduce it on the other side. (See "Drawing a Symmetrical Curve" at left).

If you need a form with two parts—a top and a bottom—for bending, you will need to account for the difference in the inside and outside radii of the curve, which is the thickness of the bent piece plus any padding, blankets, or cauls that will be placed into the form. You can increase the radius freehand. (See "Increasing the Radius of an Organic Curve" at right) or by using a compass **(Figure 4-5)**.

Once the drawing for a project is finished, I use tracing paper to make a copy and attach the copy to the material for the form to serve as a cutting pattern.

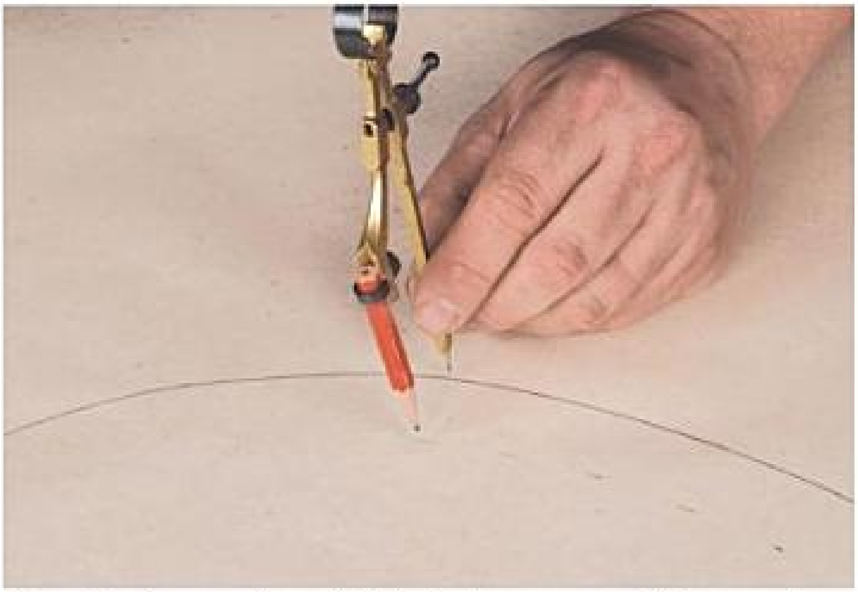


Figure 4-5. A compass is a good tool for drawing a curve a set distance away from a previously drawn line.

STEP-BY-STEP: Increasing the Radius of an Organic Curve Freehand

Try the following process for increasing the radius of an organic or irregular curve. (To increase the size of a compass curve, you can use a compass or trammel points.)

Step 1. Make a row of marks about ½" (12mm) apart and the desired distance from the original line. Be sure to rotate the ruler to follow the curve in order to create a consistent distance between the two lines.

Step 2. Then, connect the marks with a freehand line.

Form Building

Form making is often another important part in preparing to bend your project. In this section, we'll go over the tools you'll want to have handy and look at choosing the best materials for building your bending form. Then, I'll show the basics of the different forms so you can choose one that best fits your project and working style.

Tools for Forms

You don't need a lot of tools for building and using forms, but you'll want to make sure you have the essentials before beginning your project. These photos show a quick list to consider, depending on your project.

Figure 4-7. Spray adhesive and tape. Temporary adhesives, such as spray adhesive and tape, are perfect for attaching patterns.

Figure 4-6. Saws. Band saws, coping saws, jigsaws, and handsaws can be useful for cutting out forms.

Figure 4-9. Handheld router or router table. A router with a following bit can be useful for copying layers and ribs from the first layer or rib you cut.

Figure 4-8. Sanders, files, rasps, and sandpaper. All are useful for sanding and shaping the forms you build. I frequently use a disk sander, an edge sander, a spindle sander, and a handheld belt sander.

Figure 4-10. Drill. A drill is useful for fastening forms together and for drilling clamping holes in one-part forms.

Figure 4-11. Wax or wax paper. Place wax or wax paper between the caul and the outer lamination to keep the caul from sticking to the project.

Figure 4-12. Glue. A variety of glues are useful for gluing forms together. See "Adhesives" on page 64.

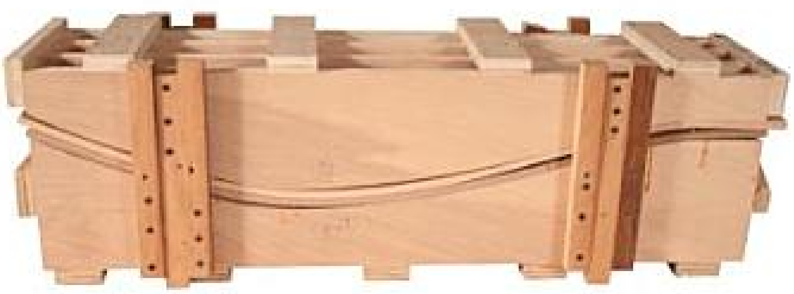


Figure 4-13. Blanket. A blanket is a wide, flexible pad that evens pressure and makes a smooth surface for a panel to rest on. Forms with ribs used for bending laminations are covered by some type of blanket or pad to span the distance between the ribs.

Figure 4-14. Cauls. Cauls are rigid members used to distribute pressure evenly. Especially with two-part forms, cauls are used in conjunction with clamps to help the upper and lower halves of the form apply uniform pressure to wood laminations.

Figure 4-15. Veneer press. Big forms can be placed into a veneer press. Though a veneer press isn't necessary for most types of bending, it can be an easy way to apply uniform pressure.

Figure 4-16. Clamps. Pressure is one of the key ingredients when using forms, and clamps are one of the easiest and most basic ways to apply pressure. Clamps are generally used with basic forms and work best for relatively narrow panels where the clamps can reach in far enough to distribute pressure over the entire panel.

Figure 4-17. Vacuum bag. Making your own vacuum bag for a vacuum press allows you to customize the bag to fit your project and can save you money. (See "Making Your Own Vacuum Bag" on page 48.)

STEP-BY-STEP: Making Your Own Vacuum Bag

Even if you are only doing flat work, you can save money by making your own vacuum bag. A shop-made bag can be used for both flat and curved work. This method becomes essential when using the outside technique described on page 58 and 59. To get started, you will need some plastic material to make the bag. The two types of plastic that work best are vinyl and polyurethane plastic (at right). In either case, the plastic should be at least 20 to 30 mil in thickness. Vinyl cement (right) works best to seal up a vinyl bag because it welds the plastic together. For a polyurethane bag, polyurethane glue, such as Gorilla Glue, will work very well. The bag can be oversized to accommodate several types of projects.

Choose either vinyl or polyurethane plastic for making vacuum bags.

Vinyl cement is ideal for making vacuum bags because it can seal any leaks.

Step 1. For most bag sizes, start with a sheet of plastic twice as wide as the width of the finished bag, and fold it over. This will give you one less seam to seal up than if you were to place one sheet over another.

Step 2. Determine where to place the valve that will evacuate the air, and make a small hole for it. Any location will probably do, but be sure to keep it out of the way of the bending form. By placing the valve near the far end of the bag, you will be able to create smaller panels by moving the bag closure closer to the valve.

Step 3. I like to use a quick coupler like the one shown here, because I have multiple bags and one vacuum pump. If the valve does not have a self-sealing mechanism like the one shown, the valve can be sealed around the edges with vinyl cement.

Step 4. To seal the long edges of the bag, lay the plastic out flat and brush on a 1" (2.5cm)-wide band of vinyl cement along the entire length. One end of the bag is always left open so it can be loaded and unloaded.

Step 5. Allow the cement to dry for about 5 minutes, or as long as the instructions on the container direct and then fold the bag in half with the glue bands on top of each other. Immediately roll over the top of the seam with a hard roller to force the two layers together.

Step 6. After the cement has hardened, I recommend you double-seal the edges. Brush a 2" (5cm)-wide band of glue on top of the bag along each edge, let it dry for the recommended amount of time, and then fold the edge over on itself. Finally, press the fold down tight by clamping a strip of wood the length of the bag over the seam. This will greatly decrease the possibility of leaks.

Step 7. To check the bag for leaks and to seal them up, load the bag with a flat panel the size of the entire bag, close off the end, attach the pump, and turn it on.

Step 8. Once the air is evacuated, you should hear a slight hissing sound around any leaks. The bag won't pull down tightly if there are leaks.

Step 9. To seal a leak, brush a little vinyl cement or hot-melt glue over the area of the leak. The suction of the pump should pull the cement into the leak and then seal the leak quickly as the cement dries. You can also press that area down or clamp it with a block.

Step 10. The bag should now be ready for use and should pull down tightly when you start the pump.

Materials for Forms

The best materials for form building are plywood and MDF. For stacking up and making solid wood forms, I sometimes use oriented strand board (OSB), which is made up of layers of large strands of wood fibers or flakes stacked in opposing layers for strength, because it is very inexpensive. For larger forms, use plywood or OSB because MDF will make a large form too heavy. Use MDF for smaller projects.

When choosing the materials for your form, make sure they are flat and void-free to prevent uneven areas in the curve. If you are using plywood, make sure it has a stable and void-free core.

Sometimes a lightweight form can also be constructed from Styrofoam, which is available at most lumberyards and builder's supply stores. Styrofoam forms are only used for panels inside vacuum bags. The dense building insulation type will not crush under the pressure of a vacuum because the pressure is distributed so evenly. The standard white type of Styrofoam, however, may not offer enough support.

Styrofoam can be cut using an electric knife or a hot-wire foam cutter. A hot-wire cutter will melt through the Styrofoam without tearing it up or filling your shop with sticky dust that can linger for weeks. Cover the surface of the Styrofoam with ⅜" (10mm) bending plywood to smooth out any irregularities and to protect the Styrofoam from denting. There can be some environmental concerns with using Styrofoam, so be sure to take all appropriate precautions. Work in a well-ventilated area and avoid inhaling any fumes.

Making Your Own Hot-Wire Cutter

A hot-wire cutter is essentially a wire with a low-voltage current running though it to produce heat. The wire is held in tension perpendicular to a surface on which the Styrofoam is fed through, much like a band saw, but without the mess. The length of the wire determines the depth of the cut the cutter can make.

There are several types of commercially available cutters or you can make your own. The key components include a low-voltage DC power supply (do not use AC, because electric shock can occur), a wire (a guitar string works well), and frame or bow to hold the wire in tension. The voltage should be between 6 and 12 volts, depending on the length and thickness of the wire. The power supply can be as simple as a battery or two or an old charger from a cell phone.

Making Forms for Bending

There are two categories of forms, or molds, that can be used to press wood into the desired shape and then hold it under pressure until the wood dries and, if necessary, the adhesive sets. The first type is called a solid form, which is made of individual pieces of material stacked together and resembles a curved block of wood. The second type, called a ribbed form, consists of evenly spaced ribs. The form you choose depends on the size of the project you plan to make, the radius of the curve, and the equipment you have in the shop. There are several variations of each type of form. I will describe the uses for and the construction of each variation.

No matter what type of form you make, you will need some extra length and extra width, usually between ½" (12mm) and 1" (2.5cm), on the form because the wood on the outside of the radius has to travel a slightly larger distance than the inside laminations do. With any type of form, take care it is as smooth as possible and the pressure you apply is uniform.

Solid Forms

Solid forms are used for solid-wood laminations, steam bending, and some narrow panels. They can become too wide, heavy, and cumbersome for wider panel work. Solid forms can be made of plywood or MDF stacked to about ½" (12mm) to 1" (2.5cm) over the desired width of the lamination. If you are using solid forms with steam bending, watch out for uneven areas, lumps, or voids on your forms, which can contribute to failure on the inside of a curve. Also, be certain the wood fibers are pressed down against the form to help keep the grain structure intact. If the fibers lose contact with the surface in any one area, they can blow out or fold there.

There are two types of solid forms—the one-part form and the two-part form—and there are variations of each.

Figure 4-18. Wood is bent around a one-part solid form, such as this one used to make the Shaker box (page 71).

One-Part Solid Forms

A one-part form is just a block of wood with one curved side for the bending wood to bend around **(Figure 4-18)**. These forms are made of layers of wood, using one of two methods: either the layers are shaped before the stack is fastened together, or the layers are stacked first and the entire stack is shaped. The latter method is faster. These methods of creating layers actually can be used to make multiple layers and ribs needed for any of the forms, solid or ribbed.

For bent laminations, glue is placed in between the laminates, and then the laminates are bent around the form. Some type of caul is usually placed on the outside of the laminations to protect them from the clamps and to evenly distribute the pressure. When using the one-part solid form for steam bending, there is usually a metal compression, or bending, strap over the outside of the curve to protect the surface and apply the proper pressure.

Figure 4-19. The one-part form for bent lamination can be made from the convex or concave shape of the curve. The holes for the clamps should be at least 1" (2.5cm) in from the edge of the curve and about 1" (2.5cm) to 3" (7.5cm) apart. The holes should fit the feet of the clamps you are using.

Figure 4-20. The holes for the clamps ensure the clamps stay square to the curve, which keeps the pressure even.

Convex or concave

A one-part form for bent lamination can have either a convex or a concave shape **(Figure 4-19)**. Some woodworkers prefer the concave shape because it can help the clamps to distribute uniform pressure reducing gaps between the layers. When using a convex one-part form, a few extra layers placed over the laminations can distribute pressure evenly. A convex form can be more easily made using a disk sander, so I usually choose this option. If you do much bent lamination, you will probably start making curves with both convex and concave shapes, so you will be using forms with both of these shapes anyway.

A one-part solid form can be used inside a vacuum bag as well **(Figure 4-21)**.

Figure 4-21. A one-part form can be used inside a vacuum bag.

Faster method

To construct a one-part solid form using the faster method, start by tracing your full-size drawing or making a copy of it to attach to the top of the stack using spray adhesive or tape. **(Figure 4-22)**. Next, cut through the entire stack just outside the final cut line, and then smooth the edge to the line on the attached drawing using a sander or hand tools.

For shaping the layers all at once, it helps to have a disk sander or an edge sander that will sand to the height of the form **(Figure 4-24)**. You can also make a jig to hold a handheld belt sander on its side or you can use hand tools to smooth out the edges. To shape the inside of a concave form, a spindle sander works well **(Figure 4-25)**.

Figure 4-22. If you're shaping each layer of your form separately, start by attaching a drawing of the curve to a layer of your form material.

Figure 4-23. When cutting the form layers separately, cut just outside the line.

Figure 4-24. A disk sander often allows you to shape the entire height of the form at the same time.

Figure 4-25. The spindle sander easily gets into concave areas.

Figure 4-26. The rest of the layers can be copied from the first layer by using a following bit mounted in a handheld router.

Shape each layer separately

To shape each layer separately, start by attaching a drawing of the curve to one layer of plywood or MDF **(Figure 4-22)**. Next, cut just outside the line using a band saw, jigsaw, or handsaw **(Figure 4-23)**. Smooth the shape of the curve to the line on the drawing using a sander or by hand. The rest of the layers can then be copied from the first layer using a following bit mounted in a handheld router or a router table **(Figure 4-26)**. The stack can be put together using nails or screws, or it can be glued together. Just make sure there are no nails or screws in areas where you are planning to make a cut or drill a hole. After all of the layers are attached together, you may need to smooth the edge of the curve a little by sanding.

Drill holes for clamps

If necessary, drill a series of holes for clamps through the entire stack at least 1" (2.5cm) in from the edge of the curve and about 1" (2.5cm) to 3" (7.5cm) apart depending on the radius of the curve **(Figure 4-19)**. Generally, the smaller the radius of the curve, the more clamps that are required to keep the laminations against the form and prevent gaps. Each hole should be large enough to accommodate the foot of your clamp. You could just place clamps across the jig without the holes, but the clamps would not be perpendicular to the curve, which would result in uneven pressure, and the clamps would tend to slip. The holes for the clamps help keep each clamp square against the surface of the curve all of the way around **(Figure 4-20)**. If you don't have a drill bit large enough to make a hole for the foot of the clamp, the back of the form can have a curve that matches the front curve. This method will also keep the clamps perpendicular to the surface of the curve. The form will need to be 4" (10cm) to 5" (12cm) thick to have enough meat to keep from flexing.

Perpendicular strips

If you are making a solid one-part form for bent laminations, attach the finished form to a sheet of plywood or MDF, and place a series of 3" (7.5cm) to 4" (10cm) long, ½" (12mm)-thick strips perpendicular to the curve. The laminations will be able to rest on these strips, and the extra glue can flow out between them. Before using the form, it is a good idea to cover the edge with wax to prevent any extra glue from attaching the laminations to the form **(Figure 4-27)**.

To clamp the laminations into a one-part convex form, you'll need to make a flexible caul to go around the outside of the curve. The band caul helps prevent the clamps from denting the wood and distributes pressure evenly, making the curve more consistent and preventing gaps between laminations. It also will help press down wood fibers on the curve's outermost surface and discourage the grain from splitting out. Each layer's inside surface will help hold down fibers on the outside of the lamination below it. The caul can be an extra lamination or two, or it can be made of any material flexible enough to bend around the curve, but thick enough to help evenly distribute the clamp pressure.

Apply center clamp

I usually start by applying the center clamp first to make it easier to bend the wood because only one half of the curve is being bent at a time. Also, when bending several layers at once, the layers will slide by each other. As mentioned above, the layers on the outside of the curve will not come around as far as the inner laminations. By lining up the laminations first and clamping them in the center, the laminations at the ends of the curve will be more even, allowing for removal of the same amount of material from each end. Add clamps and apply pressure evenly out to the ends of the curve. If the curve straightens out, flat blocks can be used as cauls to distribute even pressure along and across the laminations **(Figure 4-28)**.

Figure 4-27. Cover the edge of the form with wax to keep the laminations and the form from sticking together.

Distribute pressure evenly

To distribute even pressure to the concave area of the curve, use a fitted caul or a pliable material that will conform to a concave shape at the end of the curve. Allow the laminations to set overnight in the clamps to prevent springback.

Figure 4-28. One-part forms allow space for many clamps. Use flat blocks to distribute uniform pressure along and across the laminations.

Figure 4-29. Two-part forms for bent laminations have two parts that press the wood together. The base plate is attached to one part of the form. The cleats screwed on top keep the two parts aligned.

Figure 4-30. When clamping the form, do a dry run to be sure there are no gaps between laminations. One side of the form is attached to a plywood base with strips extending out over the other half of the form to prevent it from rising up as the clamps are tightened. The strips also help keep everything flat and even.

Two-Part Solid Forms

Two-part solid forms are made in the same way as one-part solid forms, except they have male and female sides (**Figure 4-29**). This type of form can take at least twice as long to make, but it is much quicker to use and requires fewer clamps, making it a good choice for multiple curves.

The inside of a curve for a two-part solid form can be harder to smooth out, even if you have a spindle sander. The inside and outside radii must match the curve exactly and must account for the thickness of any blankets or pads in order to decrease the chances gaps will appear between layers. Also, if the laminations are not all the exact thickness intended, the inside and outside radii will not match up, which will allow gaps to form between the laminates. More complicated forms also can be made to create complex curves that are concave on one end and convex on the other.

For the two-part solid form, using the foot of the clamp, attach the laminates to the center of the convex side of the form. This clamp will help keep the laminations centered as you begin to apply the pressure. The laminates should be lined up on the ends. Begin to pull the two sides together using clamps. When the concave side of the form reaches the foot of the first clamp, remove it and continue clamping the two sides of the form together until there are no gaps between laminations (**Figure 4-30**). You may need to loosely clamp the movable side of the form down to a plywood base to keep it from rising as the rest of the clamps are tightened. Strips extending over the form's sliding half also can be attached to the top of the form's secured half. This will help keep everything flat and even.

Figure 4-31.
Using the inside technique, both the form and laminates are placed inside the vacuum bag. Exhausting the air puts 14.7 pounds per square inch of pressure on the lamination.

Ribbed Forms

Ribbed forms are constructed of individual ribs spaced 2" (5cm) to 6" (15cm) apart. The spacing lightens up the forms and makes them ideal for making bent panels wider than the bent laminations described above. Ribbed forms can be made of one or two parts.

One-Part Ribbed Forms

One-part ribbed forms can be used to form bent panel laminations inside a vacuum bag. This process is referred to as the inside technique **(Figure 4-31)**. These forms can be used to bend panels in a variety of shapes and sizes.

For more complicated curves, such as an S curve or the W and spiral curves described in Chapter 7, "Bent Panels," on page 135, the form can be outside the vacuum bag. This is known as the outside technique.

A form used inside the vacuum bag only needs one side because the bag will conform to the shape of the outside of the curve, eliminating the need for the top half of the form **(Figure 4-32)**. A vacuum press produces a pressure of 14.7 pounds per square inch, or 2,117 pounds per square foot, at sea level—less pressure on one specific point than is produced by some screw-type presses and large clamps. A form for the vacuum press can be made using fewer ribs or it can be constructed from a variety of other materials.

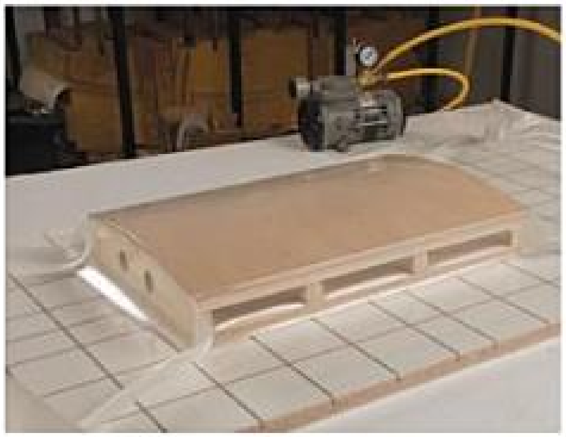


Figure 4-32.
Forms for the vacuum press only need one part because the bag conforms to the outside of the curve. The grid of saw cuts allows all of the air to flow to the exit port for the vacuum pump.

Figure 4-33. With the outside technique, only the laminates are placed in the bag. The form stays outside. The two clamped battens hold the curve against the form.

Uniform pressure = efficiency

What makes vacuum pressing so efficient for bending and veneering is the uniformity of pressure. The vacuum bag derives its pressure from the atmosphere around it trying to get in after all air has been removed from the bag. The effect is similar to the water pressure you feel when diving deep under water. The pressure comes from all directions, so there is no difference in pressure applied to the top, bottom, or sides of a curve. This is really critical for creating S curves, W curves, spiral curves, or any other type of shape that curves back on itself. These shapes are difficult to produce using traditional clamping methods, but are easy using the vacuum principle and the processes described below.

For the inside technique, where the form and the laminates are placed inside the bag and pressure is applied, the basic form is made in much the same way as the two-part ribbed form described on page 60, but with only one half. The ribs can be placed up to 6" (15cm) apart and are covered with two layers of ⅜" (10mm)-thick bending plywood. Construct the form so there are no air pockets inside; otherwise, the form could collapse under the pressure of the vacuum. Be sure to round off any sharp edges or corners that might pierce the bag. It is best to construct the form for the convex side of the curve, if possible, to help the vacuum create a more uniform curve.

Nail or screw the ribs

The ribs for this type of jig can be nailed or screwed to a board with just a few cross members to stabilize them. Two layers of ⅜" (10mm) bending plywood can be attached to the ribs with a nail gun or with screws, both to help stabilize the ribs and to act as a blanket for the laminates to rest on.

If you have a very thin, light form, you can support it by placing a smaller bag that has access to outside air inside the vacuum bag. The outside air then rushes in to push out against the inside of the bag, which is under the form. Other types of objects can serve as a form during this process including a can, a bucket, or any other smooth object that will fit inside the vacuum bag and then can have the outside-air bag placed into it.

Figure 4-34. Using a flexible mesh is key to using the outside technique and allows the laminates to bend while inside the bag.

Figure 4-35. The outside technique with a vacuum bag is ideal for shapes such as this W table. Because the shape has many different curves, it is difficult to create using other methods. This complex four-part bending form requires a vacuum bag and clamps to hold the laminations in place.

You can also bend panels and laminations inside a vacuum bag without putting the form in the bag, by using the outside technique (**Figure 4-33**). The key to making this work is to replace the stiff Melamine platen traditionally used inside the bag with a flexible mesh that allows the air to escape from the entire surface of the bag, pulling all of the layers together while the bag remains flexible (**Figure 4-34**). The bag with the laminates in it can then be bent around a form.

Figure 4-36. The W Table completed.

Speeding up the process

This technique works well for narrow strips because it speeds up the process and reduces the number of clamps required. For wider panels, outside bending allows you to create shapes that simply weren't possible in the small- to medium-size shop just a few years ago. I had difficulty trying to make a W shape before this process came along, but now I can do it easily. The technique has opened a whole list of possibilities (**Figures 4-35** and **4-36**). In addition to the one-part ribbed form, the forms for outside bending can be anything from two-part ribbed forms to a few vertical sticks to guide the shape of the curve.

Two-Part Ribbed Forms

Two-part ribbed forms are made with male and female sides (**Figure 4-37**). This type of form can be used in a veneer press or clamped with thick cauls to distribute the pressure evenly when a vacuum press is not available.

Most two-part ribbed forms are made by attaching a series of evenly spaced ribs parallel to each other, and covering them with some type of blanket or pad to span the distance between the ribs and provide a smooth surface for the laminations to rest upon. The layers of wood to be laminated are placed in between the upper and lower halves of the form, and pressure is applied. When the adhesive between the layers sets, the panel is removed, and it maintains its shape.

Remember, when making any bending form for a panel, you'll need to make it about 1" (2.5cm) wider on each end than the finished dimension of the panel to create a panel that is a little oversized on each edge. The extra width allows you to cut the panel clean after it dries to account for any shifting that may occur as pressure is applied. Also, take into account the thickness of the blankets and the lamination itself when determining the radii for the upper and lower curves because the two radii will be different.

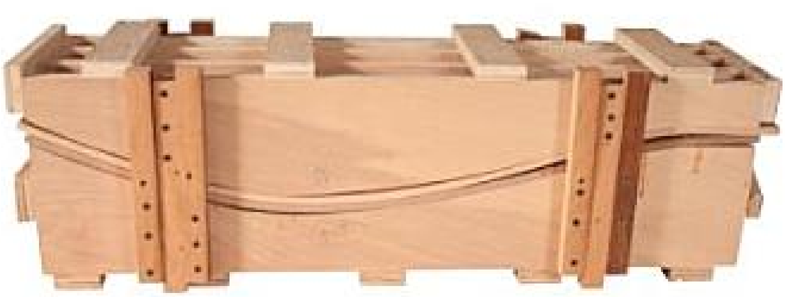


Figure 4-37. Most two-part panel-bending forms have a series of ribs for structure and support. Wood is sandwiched between the top and bottom, and pressure is applied.

Figure 4-38. Take proper care and enough time to ensure the pattern rib is accurate because it is the source of all other ribs.

Plywood brings ease

It's easiest to make two-part forms for panel bending out of plywood because MDF forms can become quite heavy. Simply attach the drawing to a piece of plywood using spray adhesive or masking tape. Use good-quality plywood with a stable and void-free core. Cut one rib to use as your pattern with a band saw or a jigsaw. Then, smooth out the pattern with files, rasps, and sandpaper (**Figure 4-38**). Because you'll use the rib to create other ribs, take the time to get it just right. You can refine the rib as you construct it. Sight along the curved line with your eye. I have found the smoothest most pleasing curve results from refining by eye rather than following a drawing exactly, particularly when you are working with a curve that is not a compass curve.

With this construction, you'll need to determine how many ribs you need to span the desired width of the panel. Allow about 2" (5cm) between the ribs for any form that goes into a veneer press or is used with clamps, and allow up to 6" (15cm) spacing for forms used with a vacuum press. Also allow a little extra width, as mentioned earlier. Count the pattern rib as one of the ribs when constructing the form.

Once the ribs are cut and shaped, they can be joined together in one of two ways. The traditional method is to first clamp the lower

ribs together and then cut a series of dadoes through them. Each dado should be the width and thickness of the solid-wood board that will join them, to make the form flush on the top and the bottom. These solid-wood boards are cut to a length equal to the final width of the form and are usually about 2" to 3" (5cm to 7.6cm) wide. They are placed about 6" (15cm) apart along the top and bottom of the form, and one is set into each end of both sides of the form.

Figure 4-39. You can join the ribs to the form with boards attached to the outside edge of the ribs.

Alternative method

Alternatively, the boards joining the ribs can be attached to the outside edge of the ribs without being set into dados (**Figure 4-39**). The first method makes the form more stable as each rib comes into full contact with the surface the form is placed on. However, I have found that if the distance from the curve to the outside of the rib is great enough, the form will be stable enough.

Figure 4-40. Guide strips help prevent the two halves of the form and the laminates from sliding around.

In either case, join the ribs together using the boards and pre-drilling all of the holes to prevent the ribs from splitting. Place temporary spacer blocks between the ribs during assembly to ensure a uniform distance between each rib. You can make just a few blocks and reuse them each time you add another rib, or you can make many spacer blocks and attach them between the ribs.

Guides prevent sliding

Guide strips help prevent the two halves of the form from sliding from around (**Figure 4-40**). They also help keep the laminates from sliding out from the sides of the form. I usually make four sets of three strips the same length as the height of the form with the laminates and blankets in place. Two sets of guide strips are placed on each side of the form at slightly different places along the length so the form can only be put together in one way. Placing the

Figure 4-41. Attach two outer strips to the form's bottom half and one center strip to the form's top half to create a set of three. The strips help ensure the form goes together correctly every time.

Figure 4-42. Regular woodworking clamps can apply enough squeeze to draw a two-part form together, bending the thin layers of wood sandwiched in between. The heavy cauls top and bottom help distribute clamping pressure.

Figure 4-43. The veneer press can apply much more pressure than regular clamps, and heavy cauls are essential to distribute the pressure.

strips this way eliminates headaches during the heat of the glue-up. For each set of three strips, attach the two outer strips to the bottom half of the form, and attach the one center strip to the top half of the form (**Figure 4-39**). Place a strip of veneer between all of the strips to allow enough room for the form to go together and pull apart easily. It's easier if you clamp all three strips together with the veneer between them, then clamp that unit to the form, and predrill and screw the strips down before finally removing the clamps. Be sure the strips are square to the form for easy assembly and separation.

Attaching blankets

Blankets can be attached to the form with one screw along the center of each edge to streamline the process of placing everything in form as the glue is setting. I usually use two layers of ⅜" (10mm)-thick bending plywood on the top and on the bottom of the form as blankets. This form is now suitable for clamping with large cauls or for pressing in the veneer press (**Figures 4-42** and **4-43**).

Free-Form Bending

An older method for creating linear bent laminations that curve and twist through space uses bicycle inner tubes twisted around the laminates to press them together. Seth Stem, one of my teachers at Rhode Island School of Design, used the process, which I call "free-form bending."

He would use a series of vertical strips as reference points to clamp the laminates. The length of the laminate between each vertical stick can be twisted, raised, or lowered to create compound curves. The inner tubes are wrapped around the laminates to pull them together. He worked his way from one end of the curve to the other, twisting, clamping, and wrapping all at the same time. Urea formaldehyde glue is excellent for this procedure because it allows plenty of time to work and dries very hard. After they are dried, the laminates are shaped by hand with files, rasps, and sandpaper. The laminations also can be pressed together using a series of shop-made clamps placed along the length of the twisting curve. Each clamp consists of two strips of hardwood or metal longer than the width of the laminations. The strips are joined by bolts on either end. Tightening the bolts presses the laminations together.

Adhesives

There are a variety of adhesives from which to choose depending on the specific application. The most important qualities for an adhesive to possess for wood-bending projects are a long open time (the time you have from applying the glue until it starts to stick), and the hardness of the glue after it sets. It usually takes some time to apply glue to all surfaces, get the panel into the form, and finally apply the necessary pressure. A glue that dries very hard will help prevent the curve of the panel from relaxing or springing back. A good way to test the hardness of any glue is to pour some out onto a sheet of paper or plastic and let it dry for a day or two. After that time, pick up the dried puddle of glue and try to bend it. If the glue bends easily, it will most likely allow some springback. If the puddle of glue shatters or breaks when you try to bend it, the glue should dry very hard and will probably allow a minimum amount of springback.

Here, we'll cover the two basic categories of adhesives: thermoplastic and thermosetting.

Thermoplastic adhesives

Thermoplastic adhesives dry by evaporation, when molecules of water are released. The process can be accelerated with heat, which, in essence, cooks off the water molecules. Thermoplastic adhesives can be remelted, softened, and then reset. This property is utilized for hammer veneering described in Chapter 8, "Finishing the Edges of Bent Panels," beginning on page 169.

One category of thermoplastic adhesives is polyvinyl acetate (PVA) glues. White and yellow glues, such Titebond II, Titebond III, and most brands of ready-to-use woodworking glues, are types of PVA glues **(Figure 4-44)**. Stick to yellow glues formulated for wood. White glue, such as Elmer's glue, will not dry hard enough to prevent springback **(Figure 4-45)**.

Figure 4-44.
PVA glues designed for woodworking are good choices for wood bending.

Titebond II works well for large-radius curves made from material that bends easily. However, it has an open time of only about 5 to 10 minutes, which may cause it to grab too fast for some bending operations. Titebond III (**Figure 4-46**) works very well for most medium-radius curves. It has a good balance of strength, ease of application and cleanup, versatility, and is relatively inexpensive. This glue dries hard enough to use for bent panels without the curve relaxing, provided the curve does not have an extremely small radius. Its open time is about 5 to 12 minutes, depending on the temperature of the shop. Titebond III is also very water resistant and can be used for some outdoor applications. I use Titebond III for most of the bent panels I make in my shop because most of them do not have a tight radius or contain more than a few layers. All of these types of glue can be spread with a roller, brush, or with a notched trowel.

Thermoplastic adhesives will adhere to most types of substrates and veneers, but they do not adhere well to oily woods such as rosewood and teak. These adhesives are generally non-toxic and can be cleaned up with soap and warm water. The heat in the workshop must be at least 60° for PVA adhesives to set properly. If the adhesives are to work properly for bending, the panels need to be left in the form under pressure for at least 12 hours to prevent springback and delamination, or the separation of the layers within a plywood panel. Delamination is usually caused by not enough pressure on a particular area, not enough time under pressure for the glue to set properly, or an insufficient amount of adhesive.

Figure 4-45.
Although it is a PVA glue, regular white glue, such as Elmer's, does not dry hard enough to use for wood bending.

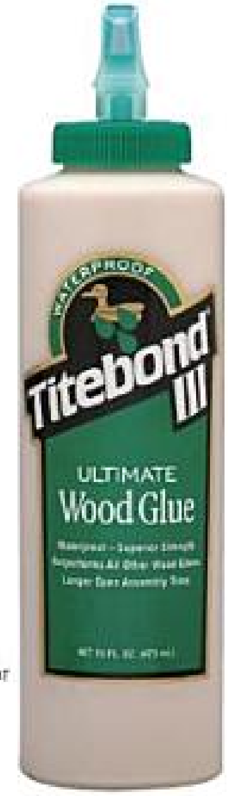


Figure 4-46.
Titebond III is an excellent choice among PVA glues for wood bending.

Thermosetting adhesives

Thermosetting adhesives dry by chemical reaction that occurs when two parts are combined, when water is added, or when heat is applied. They can be toxic, so be sure to wear a dust mask or a respirator when mixing and applying them. Thermosetting glues will, as a rule, dry much harder than thermoplastic glues, which can all but eliminate springback. Some types of thermosetting glues allow for a very long open time, and some are extremely water resistant.

Figure 4-48. Epoxy is strong, water-resistant, and dries hard. Some epoxy formulas have a long open time.

The most commonly used type of thermosetting adhesive is urea formaldehyde, or plastic resin, glue. It is used in the manufacture of plywood, MDF, and other composite materials, and to adhere face veneers to these materials. Other less toxic organic compounds are beginning to be used in place of urea formaldehyde adhesives in manufacturing.

Urea formaldehyde glue is available in two forms: a powder mixed with water when ready to use, and a two-part formula that is also mixed when ready for use. The powder type of urea formaldehyde glue that can be found in most hardware stores is called Weldwood plastic resin glue (**Figure 4-47**). In my own shop, when I need more open time or a harder glue, I will most often choose this type of glue. The type of urea formaldehyde glue that is mixed in two parts also dries very hard and is even more water resistant than the powder form. Both types of urea formaldehyde glue allow up to 15 to 20 minutes of open time in a cool shop. Using cool water to mix up the powder type of urea formaldehyde glue can increase the open time to 25 to 30 minutes.

Figure 4-47. If you need glue that dries hard and has a long open time, try urea formaldehyde.

Panels glued with both types of this glue need to stay in the form and under pressure for at least 12 hours. This time can be decreased greatly by the addition of heat. In manufacturing operations, the time can be reduced to a just few minutes using high heat and radio waves focused right on the glue lines. Urea formaldehyde dries to a light brown color, which works well for darker woods. Both types can be spread with a roller, brush, or notched trowel and can be cleaned up with soap and warm water before they set.

Epoxy and resorcinol

Other types of thermosetting glues that work well for laminating bent panels include epoxy and resorcinol. Epoxy resists water very well and is often used in boat construction, both for wooden boats and as the adhesive that holds fiberglass together **(Figure 4-48)**. It dries clear or can be tinted with fine sawdust, wood flour, or special tinting agents, and it will stick to almost anything. Epoxy dries very hard, and some formulas allow for up to 1 hour of open time. A good rule of thumb is the slower the epoxy sets, the stronger it will be. This is because quick-setting epoxies have a lower percentage of bonding resins and a higher percentage of hardeners. Be careful when using epoxy to bond surface veneers, because it can seep through to the surface. There is a fabric treated with a release agent available. When using a vacuum bag, the release fabric is placed over the panel to prevent any epoxy that seeps through to the surface from sticking to the bag, the cauls, the form, or any mesh material that might be used. Epoxy can be applied with a roller, brush, notched trowel, or sprayer. The most commonly used cleaners for epoxy are denatured alcohol, mineral spirits, and acetone. Denatured alcohol is one of the safest if you are concerned about contact with your skin, and regular mineral spirits are relatively safe. Acetone evaporates quickly, so take any necessary precautions when using it. Many cleaners are flammable, so always guard against fire hazards. Also, always follow the instructions on the epoxy you use.

Resorcinol **(Figure 4-49)** is also extremely water resistant and is commonly used for boatbuilding and other outdoor applications. It is mixed from two parts and has an open time of about 20 minutes. Resorcinol dries very hard, which makes it a good choice for many bending applications. However, it dries to a dark brown color so it is not appropriate for lighter woods. It can be applied with a roller, brush, or notched trowel and can be cleaned up with soap and warm water before it sets.

Figure 4-49. Resorcinol dries hard, making it a good choice for many bending applications. However, its dark brown color is not appropriate for lighter woods.

Glues for Bending Wood

Adhesive	Type	Radius Used	Open Time	Drying	Application	Other Features
Titebond II	Thermoplastic	Large-radius curves	5–10 minutes	Dries Hard	Roller, Brush, or Trowel	Somewhat Water Resistant
Titebond III	Thermoplastic	Medium-Radius Curves	10–15 minutes	Dries Hard	Roller, Brush, or Trowel	Good Water Resistance
Urea Formaldehyde	Thermosetting	Small-Radius Curves	15–20 minutes	Dries Very Hard	Roller, Brush, or Trowel	Somewhat Water Resistant
Epoxy	Thermosetting	Small-Radius Curves	Long Open Time up to 1 hour	Dries Very Hard	Roller, Brush, Trowel, or Sprayer	Excellent Water Resistance, Dries Clear
Resorcinol	Thermosetting	Small Radius Curves	20 minutes	Dries Very Hard	Roller, Brush, or Trowel	Excellent Water Resistance

CHAPTER 5

Bending with Heat, Water, and Steam

Adding heat, moisture, or just the right combination of the two to certain species of dried wood can make them bend like a noodle **(Figure 5-1)**. The process can be as simple as spraying the surface of a piece of thin wood with water and bending it over a hot iron, or it can be quite complicated when steam bending a thick piece of wood.

In this chapter, I'll start by demonstrating how to bend thin wood with just a little heat and moisture added to create an oval Shaker box. Then, I'll go to the other end of the spectrum and explain in detail how to bend a 1" (2.5cm)-thick piece of oak using a steam box.

Figure 5-1.
The right combination of heat and moisture makes it easy to bend many thin woods. This mahogany guitar side is being bent over a shop made hot pipe setup.

Bending with Water and a Bending Form

Apart from hand-bending green wood, bending with water and a bending form is the simplest method for bending wood, typically employing thin strips of wood. As has been described in other parts of this book, wood cut into thin strips will usually bend quite easily to a medium radius without the addition of heat or moisture. In the case of some bent laminations, the moisture from the glue alone can help soften the wood enough to aid in bending. However, adding just a little water, will help further soften the lignin, the flexible glue in wood, which enables the wood to bend more easily. We typically add moisture to thin strips by spraying them with water or by allowing them to soak in warm water. Sometimes, ammonia is added to the water to make the wood even more pliable. Wood can be further softened by boiling it in water.

The Shaker Box

A Shaker box is a simple yet attractive project you can make using water and a bending form. It requires minimal tools and materials, so it is a great beginning project. To make the box, the strip of wood for the body will have to bend around a small radius (**Figure 5-2**). The traditional method for softening wood for the box is to soak or boil it and then quickly bend it around a constructed form. After the box has been removed from the form and allowed to dry, the overlapping sides are joined using copper nails or rivets. The bottom is then attached, and the curved lip of the top is bent around the sidewall and assembled in the same manner as the side.

Making the Form

To make the outside form (**Figure 5-3**) we'll need for the box, we'll start by creating a full-size pattern. Because the oval is symmetrical, we can use the technique described in "Drawing a Symmetrical Curve" on page 44.

Wood-Bending TERMS

Anvil. A hard, metal surface used as a support upon which projects can be hammered.

Bending iron. A commercially available or shop-made device with a variable heat source applied to a curved surface around which the wood can bend.

Bending machine. A heated, curved form with movable clamps and metal cauls used to form the curved sides of a guitar.

Bending strap, or compression strap. A metal strap placed on the outside of a curve with blocks that fit against the ends to keep the wood fibers in compression and help prevent the wood from splitting and cracking.

Billet. A rough-sawn or split piece of green wood ready to be air-dried or is already air-dried.

Cleat. A block of wood attached to the form's bottom so it can be clamped in a vise.

Flange. A metal fitting used to attach the end of a round pipe to a flat surface.

Interlocking grain. Grain traveling in different directions in relation to the wood's surface.

Rheostat. An electronic switch that regulates the flow of electricity.

Steam box. A container built to allow steam to surround and moisten wood.

Veneer. A thin slice of wood.

Wattage capacity. The amount of electricity that can safely flow through a wire or switch.

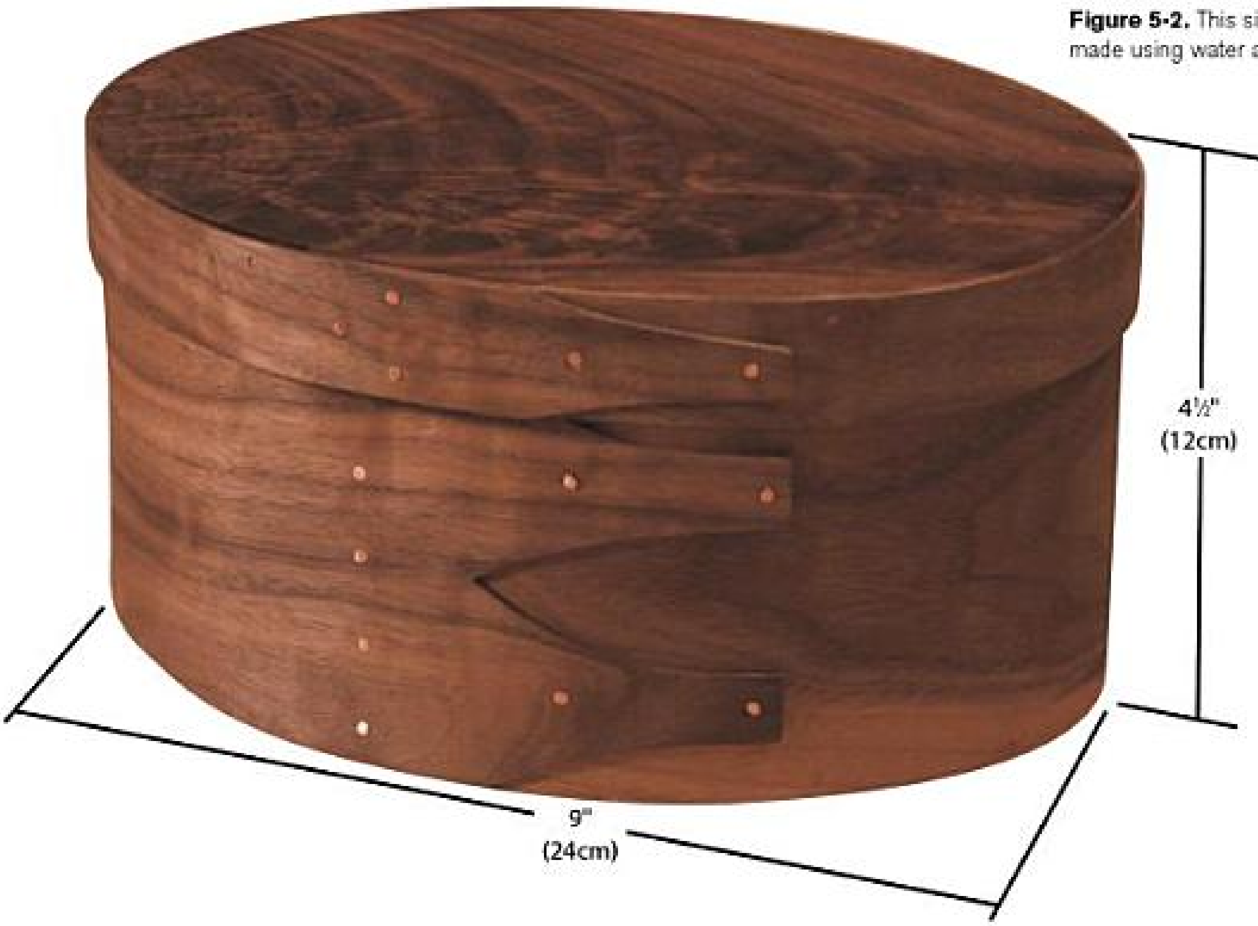
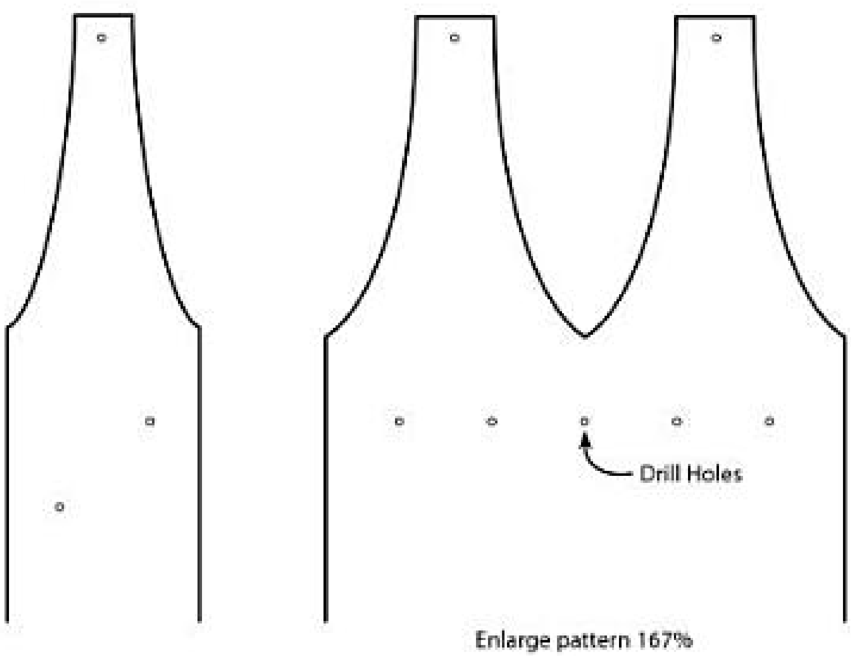


Figure 5-2. This simple Shaker box is easily made using water and a bending form.

Shaker Box Pattern



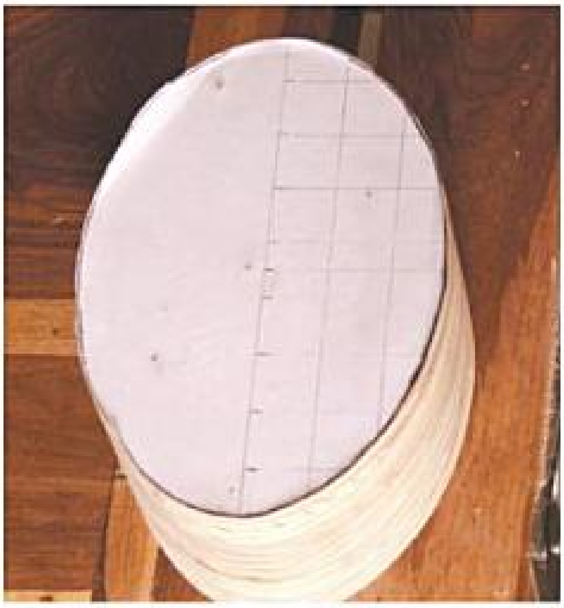
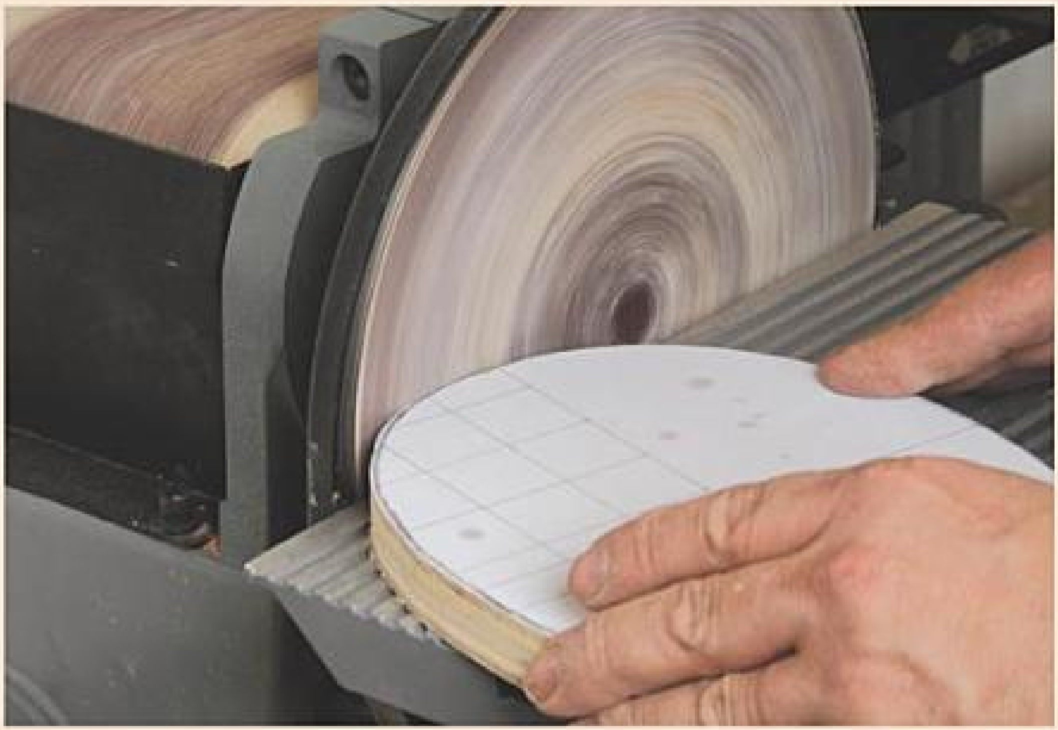


Figure 5-3. The first step in making an outside bending form, such as this one, is creating a full-size drawing.

DEMONSTRATION PROJECT: Making the Form for the Shaker Box

To begin making the form, you will need to make a full-size drawing of the oval shape. Follow the steps on page 44 to freehand draw a pleasing oval. The form to bend the side of the box can be constructed from stacked pieces of MDF, plywood, or other similar material.

Step 1. After preparing your oval, shape the piece using a disk sander. Make sure it is just as you want it so you can use it to create the other layers for the form. If you don't have a disk sander, clean up the piece with hand tools and sandpaper.



Step 2. Use the pattern piece to draw the rest of the layers on the material. You need enough pieces so that when stacked, they create the desired thickness for the height of the form. I made my stack 4½" (12cm) thick, which was the thickness of six sheets of ¾" (20mm) material.

Step 3. Screw or nail all of the pieces together in a stack. Then, use a disk sander around the edges and smooth the form, using the layer with the drawing attached as a reference. If you don't have a disk sander, use hand tools and sandpaper to clean up the stack.

Step 4. After the form has been shaped and sanded, attach a block to the bottom. The block will be used to secure the form in a vise as you bend the wood around it.

Figure 5-4. Veneers are thinly cut wood slices that can make great material for bending projects. They come in quite a few species and thicknesses.

Selecting and Preparing Wood for the Box

As with any bending project, when selecting the wood for the sides of this box, try to find wood with the grain running parallel to the surface to prevent splitting. However, keep in mind that many types of wood, with a variety of grain patterns, when cut thin enough, will bend to a small radius if soaked or boiled first. For this reason, you may want to experiment with several woods before making your box.

The thickness of the wood will depend on the size and the radius of the box and the species of wood that you choose. Wood for construction of most Shaker boxes ranges from 1/16" (1.5mm) thick for small boxes to 3/16" (4.5mm) thick for large boxes. A 1/16" (1.5mm) thick veneer, in a limited number of species, is available from most veneer suppliers (**Figure 5-4.**). Precut strips and box kits also are commercially available. If you are planning to cut your own wood strips, follow the procedure described in "Using a Band Saw" on page 121. A thickness sander will help greatly to get the sides down to their final size without tearing them out. The box shown in this chapter is 9" (23cm) long by 4½" (11cm) tall. The wood is 3/32" (2.5mm) thick.

After choosing the wood, it must be prepared before soaking it for bending. I like to start by making a paper, cardboard, or plastic pattern the size and shape of the bentwood side to make sure everything lines up perfectly. See the directions in "Preparing the Wood for the Box" on page 75.

DEMONSTRATION PROJECT: Preparing the Wood for the Box

Properly preparing the wood before soaking it is important for getting just the right fit. I find making a pattern helps check the process to ensure everything goes smoothly.

Step 1. Cut paper, cardboard, or plastic to the size of the bent wood side.

Step 2. Make a registration mark on the form and the pattern to determine the length of the pattern and the starting and stopping points of the bent side.

Step 3. Draw the shape of the fingers for the sides and cut them out using scissors or a knife.

Step 4. Smooth and shape the pattern with 80- to 120-grit sandpaper as needed. If you plan to use tacks to fasten the side together, measure and mark where the holes need to be drilled. (See the pattern on page 71.)

DEMONSTRATION PROJECT: Preparing the Wood for the Box

Step 5. Make the wood for the side about ⅛" (3mm) longer than the thin paper pattern to account for the thickness of the wood when bending.

Step 6. Use blue painter's tape to attach the pattern to the wood. Trace the shape of the fingers onto the wood. You can stack several layers of wood together if you plan to make multiple boxes.

Step 7. If you plan to use tacks to fasten the side together, use the marks you made earlier to predrill the holes on what will be the outside layer to prevent the wood from splitting. Drill right through the pattern and into the wood. Remember to use a scrap piece as a backing board.

Step 8. Cut the end fingers of the box side with a knife, coping saw, band saw, or scroll saw. If you are cutting several box sides at once, use a band saw, jigsaw, or handsaw.

Step 9. Sand both sides of the wood strip now because sanding will be difficult once the box is assembled. The fingers can also be cleaned up with sandpaper. You may want to bevel the edge around the fingers or add some other detail to make a more pleasing design.

The Bending Process

Once the box side has been prepared, we're ready to add moisture to the wood. The wood can be softened for bending in two ways—it can be boiled for about 5 to 10 minutes, or it can be placed in a tray with boiling water added and then soaked for about 10 to 20 minutes, depending on the thickness. Whenever you are working with boiling water or heat in bending, protect your hands with leather gloves (**Figure 5-5**). The demonstration project "Bending the Box Side" below shows the complete process.

Figure 5-5. Heat-resistant work gloves are essential safety gear for steam bending.

DEMONSTRATION PROJECT: Bending the Box Side

In this step-by-step sequence, I'll show you how to soften wood using a tray and boiling water. Once you have finished the steps below, you must leave the box overnight to dry before fastening it together.

Step 1. Place the wood in a tray and add boiling water. Allow the wood to soak for about 15 minutes or until it is soft.

Step 2. Remove the side from the water, and quickly bend it around the form. Wear leather gloves. A reference mark on the form indicates where the wood strip begins.

Step 3. Place a clamp across the form to help the wood keep its shape as it dries. Make sure to use a clamp pad to prevent the clamp from denting or staining the wood, being careful not to dent the wood with the clamp block. Leave the box side clamped for a few minutes until the outside surface has dried.

Step 4. Make a mark on the edge of the side where the wood ends to make sure the final circumference of the box will match the original drawing. Then, remove the box from the form and clamp it with a spring clamp or two until the wood is fully dry, usually overnight. To prevent mildew from forming on the inside of the box, do not leave the box on the form overnight.

Figure 5-6. To make this shop-made anvil, clamp two blocks of wood together and drill a hole, centered on the joint that is just smaller than the pipe. Then, unclamp the wood, insert the pipe, and screw the two boards back together.

Figure 5-7. This shop-made drilling jig holds the drill at the proper height perpendicular to the box. A wing nut makes it easy to loosen the metal strap and remove the drill.

The Box Assembly

After the wood has dried, the side can be fastened together with copper nails or rivets. Copper nails are difficult to find, but they are available from marine suppliers. Rivets and other types of fasteners are readily available. Whenever you are applying tacks, place the box over an anvil. You can use a shop-made anvil similar to the one shown here **(Figure 5-6)**.

There is no glue used in this basic box project, as in the traditional method for constructing Shaker boxes.

Assembling the box also includes creating and attaching the top and bottom. The thickness of the wood for the top and bottom of the box is usually no more than ½" (12mm) thick for larger boxes and less for smaller boxes. To drill the holes for attaching the bottom, I made a small horizontal drill jig that holds a drill at the proper height to drill through the center of the box bottom **(Figure 5-7)**.

Mount the drill to a board to create the small horizontal boring machine. A small table for the box and the lid to sit on is made the proper height so the drill bit is centered on the thickness of the solid-wood top and bottom. Secure the drill so it doesn't move as you push the box into the bit. I used a metal strap secured with a wing nut so the drill can easily be taken in and out. Blocks mounted against the drill can also help stabilize it.

DEMONSTRATION PROJECT: Assembling the Box

As I show you how to fasten the side in this demonstration, I will describe how to use copper nails because they are the traditional means of joining the sides of Shaker boxes. I'll also go over how to make the top and bottom.

Step 1. Fasten the side with the tacks, using the holes you drilled earlier. Each tack should pass through both layers of wood and mushroom out on the inside, much like a rivet, as it is hammered against the anvil. Make sure the mark made earlier to determine the circumference of the oval is still lined up.

Step 2. To make the bottom of the box, trace the shape of the original form onto the wood, cut it out, and smooth the edge. A disk sander or an edge sander works well for the final fitting.

Step 3. Make sure there is a tight fit all around by forming the wood around the bottom rather than risking losing the oval shape by trying to match the shape of the bottom to the bend. Sand both sides of the bottom before assembling the box.

Step 4. Using the jig, start the drill and push the box into the bit. There is a pencil line drawn on the base of the jig to determine the depth of each hole.

Step 5. Tapered round toothpicks or very small dowels act as nails to fasten the side and the bottom together.

Step 6. Sand off the ends of the dowels and proceed to making the top.

Step 7. To make the band that goes around the top of the lid, cut out a blank and soak or boil it in the same manner as the side. Cover the box with plastic and bend the top band around the bottom of the box.

Step 8. Clamp the band in place and allow it to dry.

Step 9. To determine the shape of the solid wood for the top, place the box on the solid wood and draw around the outside. When cutting out the wood for the top, stay at least 1/16" (1.5mm) outside the line. This will make the top slightly larger than the side, allowing the top to go on and come off easily.

Step 10. Use the same procedure used to nail the side together to attach and finish the top.

Bending with Heat

Another easy way to bend wood is with heat. This method also typically employs thin strips of wood. Heat alone will help soften the lignin in certain species of wood when it is cut thinly. However, as the wood to be bent gets thicker and the radius tightens, moisture will need to be added in combination with heat to soften the lignin deep inside the wood so the fibers can more easily stretch and compress. The combination of water and heat forces steam into the cell walls, softening the lignin and making bending easier. The moisture also helps greatly to conduct and retain the heat.

When using this method, we typically add moisture to the strips by spraying them with water or by allowing them to soak in warm water. Then, we apply heat with a bending iron.

Making a Bending Iron

Bending irons can be purchased or shop made. I have illustrated two methods for making your own bending iron here, and I'm sure there are more, depending on the materials available and the ingenuity of the maker. All you really need is a variable heat source applied to a curved surface around which the wood can bend.

The most common type of shop-made bending iron uses a propane torch as a heat source **(Figure 5-8)**. It can be placed in a vise to hold it securely as the wood is bent around it. The pipe is attached to a board with a flange. Washers are placed in between the flange and the board to keep the board from getting too hot **(Figure 5-9)**. A cap with several holes drilled in it helps retain the heat **(Figure 5-10)**. Adjusting the propane torch regulates the heat level. Some very small curves can be created using a bending iron made of 1" (2.5cm) pipe **(Figure 5-11)**.

Figure 5-8. This bending iron heated with propane was constructed from parts I already had in my shop.

Figure 5-9. Washers prevent the board from getting too hot.

Figure 5-10. Drill holes in the cap to help retain heat.

Figure 5-11. A few examples of the tight curves that can be created with the 1" (2.5cm) propane bending iron.

Figure 5-12. This shop-made bending iron is constructed from an electric charcoal lighter.

Figure 5-13. The standard light dimmer I used has a wattage capacity larger than the load drawn by the charcoal lighter.

Figure 5-14. Sheet metal, pipe, and stovepipe all make suitable covers for the heating element.

If you are uncomfortable with burning propane in your shop, you can make a bending iron made using an electric charcoal lighter with a rheostat to regulate the temperature (**Figure 5-12**). I made this type of iron using an electric standard light dimmer with a wattage capacity larger than the load drawn by the charcoal lighter (**Figure 5-13**). The heating element can be covered with sheet metal, pipe, or stovepipe (**Figure 5-14**).

Using a Bending Iron for the Shaker Box Sides

Instead of using just water and a form to bend the side for the Shaker box, as described on page 77, you can use a bending iron like the ones described on pages 81 and 82 to bend the side. Soak the wood in a tray with warm water or keep it moist for about 15 minutes using a spray bottle with water, similar to the method we used for bending the side around the form earlier (page 77). Bend the wood around the form a little at a time going back and forth from the bending iron to the form. (**Figures 5-15**). After it has been shaped, the box side can be nailed together right away or it can be clamped and stored until ready for completion. (**Figure 5-18**).

Continuing the Bend

Figure 5-15. You can bend the side of a Shaker box using a shop-built electric bending iron. The finished box was made of 3/32" (2.5mm) mahagony wood I planed and sanded down in a thickness sander.

Figure 5-16. Again check the curve of the Shaker box side after you have spent more time bending the wood with the iron.

Figure 5-17. After several passes, you can see how the wood really starts to bend.

Figure 5-18. The box side can be clamped and removed from the form for completion later.

Figure 5-19. You can create the sides of a guitar, such as these made from curly maple, using a bending iron and a form.

Figure 5-20. There are many ways to make the sides for a guitar. The sides of this guitar are flame maple, the top is quartered spruce, and the neck is maple, all made by Bob Saunders of the Prairie Rose Woodworking Studio in Indianola, Iowa.

Bending a Guitar

Using a bending iron and a form is also common for creating some parts of a guitar (**Figure 5-19**). There are three basic methods to bend the sides of a guitar—using a form on the outside of the guitar body, using a form on the inside of the body, and using a bending machine (**Figure 5-20**). For the first two methods, the wood is heated with a bending iron, as described for the Shaker box on page 83, and then fitted to a form. You can also purchase a bending machine (**Figure 5-21**). (See the "Resources" section on page 179 for more information.) The added support of the compression, or bending, strap used with the bending machine will allow you to repeatedly bend highly figured woods to a consistent shape. All three techniques can be adapted to produce many types of musical instruments, boxes, baskets, and other projects.

Though there isn't sufficient space in this book to detail the entire process of constructing a guitar, I will discuss all three methods for creating the guitar body in order to give you an idea of how they work and some background for other uses of these processes. Bob Saunders of the Prairie Rose Woodworking Studio in Indianola, Iowa, demonstrated for me two methods for forming the sides of guitars he was making in his shop. I thank him for his help.

Choosing a Method

When choosing which method to use to bend the side of a guitar, you will need to consider the following:

Consistency. Do you want to reproduce many bent pieces to an exact size and shape, or just one? If you want to produce many pieces, a bending machine might be the most cost-effective and efficient method, and it might yield the best results.

Expense. Do you want to spend the money on a bending machine, or do you want to make the form yourself in the shop? What type of wood are you planning to use? A highly figured wood with interlocking grain may require more of a support strap than a more even-grained wood, which might rule out the bending-iron method.

Time. Do you want to take the time to make the form? You may want to put yourself on a different clock when constructing musical instruments because they do take a lot of time, and taking short cuts with musical instruments rarely ends with a positive result.

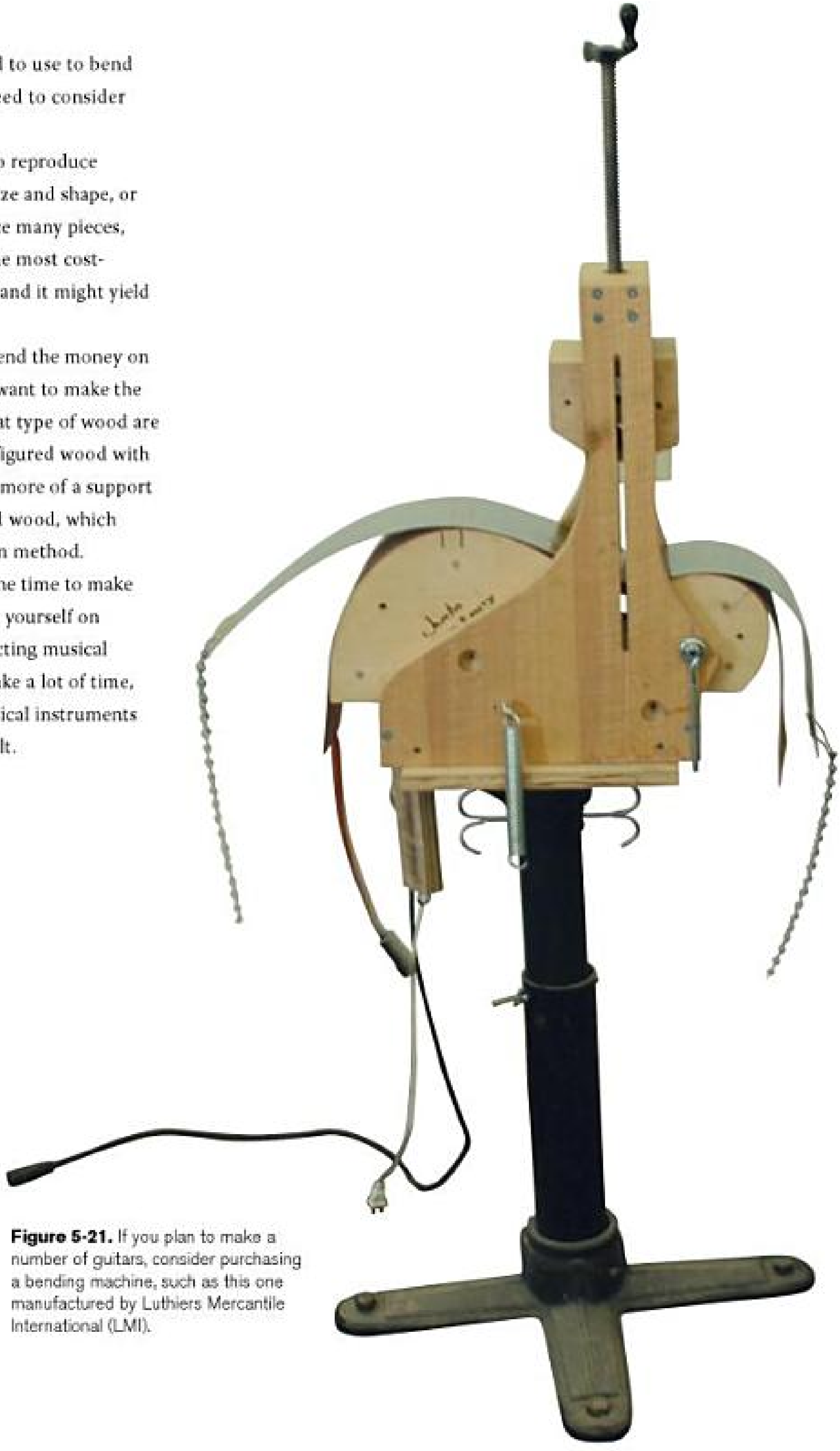


Figure 5-21. If you plan to make a number of guitars, consider purchasing a bending machine, such as this one manufactured by Luthiers Mercantile International (LMI).

The Tormek machine uses a universal tool rest that can be mounted on the top or the front of the machine, as shown in **Figure 10-32**. It is essentially a steel bar to which all of the various jigs and fixtures are attached. These hold the tool or cutter at a specific angle from which it cannot deviate. This enables forming a uniform edge because the jig both establishes and then maintains the required angle.

There is some adjustment in almost every Tormek jig, and the tool rest is micro-adjustable. The adjustment is necessary because not all blades have the same dimensions. This is perhaps the only aspect of the Tormek system that is not completely intuitive—it requires a little experience and judgment. However, the company provides a comprehensive, well-written, 150-page manual with hundreds of crystal clear instructions and also offers support through their Website. Tormek's literature uses perfectly acceptable definitions of grinding and honing that may be confusing to American ears: Grinding seems to include everything up to final stropping on a leather wheel, which they term "honing."

Courtesy Tormek®

Figure 10-31. Most jigs for a Tormek attach to the universal support, a bar that can be placed on top or in front of the unit.

M.Power Sharpener

Not strictly a "machine" because it isn't motorized, the M.POWER Precision Sharpening System (PSS1), shown in **Figure 10-30**, is a tough, aluminum device that includes two DMT monocrystalline diamond abrasive stones. The base of the unit holds a blade or chisel stationary while the top, set at a fixed angle (25 or 30 degrees), guides the diamond abrasive across the tool's bevel. Included are a prep stone and a finishing stone. The geometry of the gadget means that the sharpening action takes place parallel to the cutting edge, which is 90 degrees different from other sharpening machines. This is just about the simplest sharpening device on the market, and certainly one of the most effective. It is almost as fast as a bench grinder for creating or maintaining a primary bevel, prior to establishing a secondary one with a fine polishing water stone.

Courtesy M.Power Tools

Figure 10-30. The DMT M.POWER PSS1 is a tough, aluminum device with two monocrystalline diamond abrasive stones.

Woodtek

The Woodtek water-cooled sharpening machine (see **Figure 10-32**) was designated a "top value" by *Wood* magazine in 2002. The compact unit takes up less than one square foot of bench space. The 7"-diameter, 1,000-grit wheel spins at 420 rpm for very smooth, precise sharpening. An adjustable built-in guide makes it easy to set the correct angle for any type of edge. It weighs 13 pounds and will accommodate a range of stone grits. The Woodtek sharpener is quite inexpensive. I purchased one a couple of years ago and ordered a second, 400-grit wheel for more aggressive grinding, with impressive results. As

Photo by author, permission of woodworker.com

Figure 10-32. The Woodtek water-cooled sharpener spins at 420 rpm and comes with a 1,000-grit wheel.

been largely replaced with Indian rosewood. The sides of a quality guitar body are constructed of a single thickness of wood measuring about .1" (2mm) thick, or slightly less **(Figure 5-23)**. Cutting wood this thin allows for the use of many species of wood that wouldn't bend well if they were cut thicker. Good tonewoods that can be bent in this relatively thin state include cypress, mahogany, figured maple (which is referred to as flame maple by instrument makers), quilted maple, and rosewood. Some of these woods are listed as difficult to bend in the "Wood Bending Properties" table on page 24. However, if these woods are cut thin enough and properly handled, they can indeed be bent with heat and a small amount of moisture to create a guitar with a rich, beautiful sound. Violins and other stringed instruments are most often made with bodies of European curly or tiger maple or, in the United States, of curly western big-leaf maple. Wood used to create violins, violas, and other small stringed instruments is cut considerably thinner than wood for a guitar **(Figure 5-24)**. Extra care needs to be taken when bending some of the more highly figured of these woods due to their interlocking grain patterns.

Figure 5-23. The guitar's sides are constructed of a single thickness of wood.

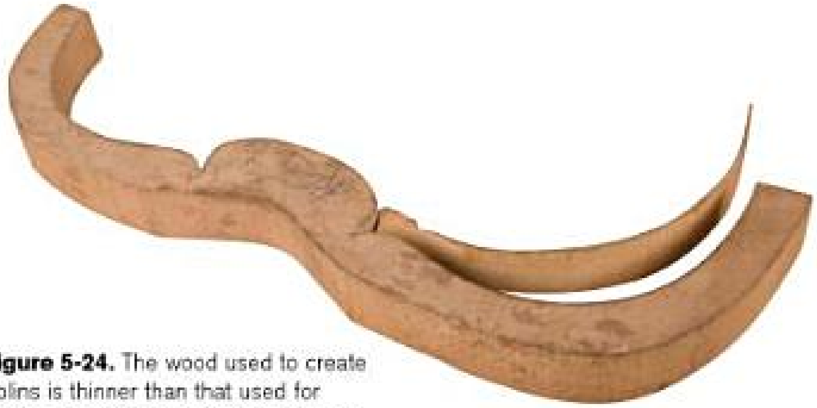
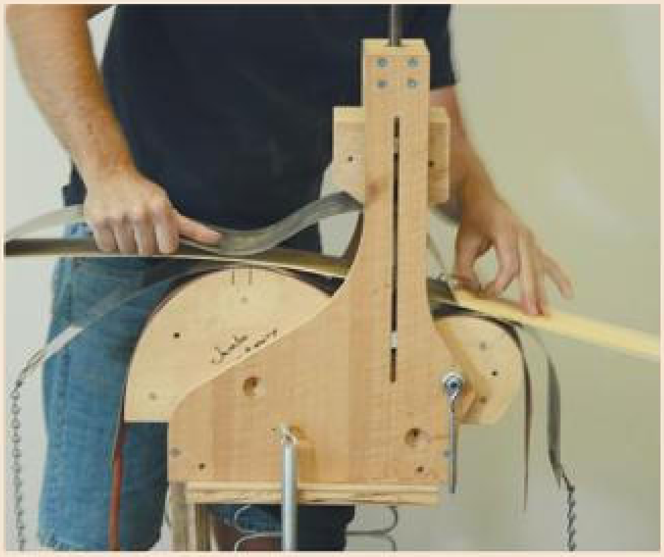


Figure 5-24. The wood used to create violins is thinner than that used for guitars. This form for a violin side was made by my great-grandfather. You can see how the form works with one curved element in place.

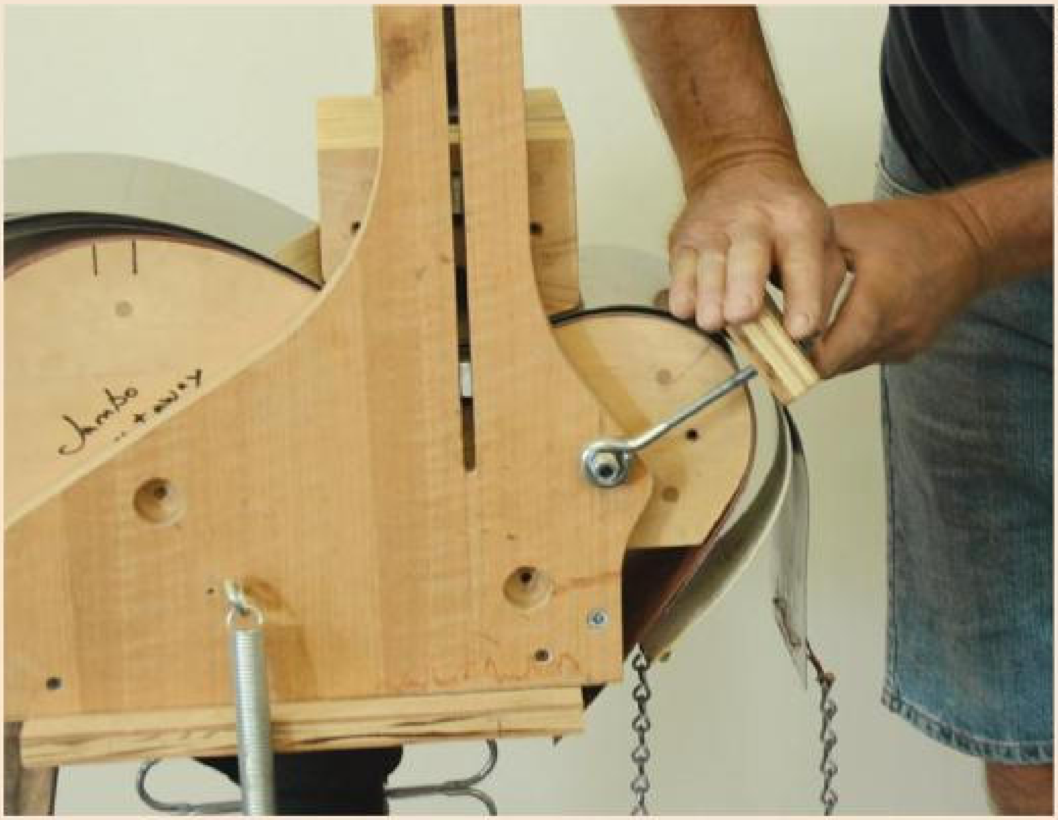
STEP-BY-STEP: Bending Guitar Sides with a Bending Machine

Start up the bending machine when you're ready to wet the wood. The bending machine takes about 15 minutes to heat up, which is about the same amount of time it takes to fully moisten the wood.

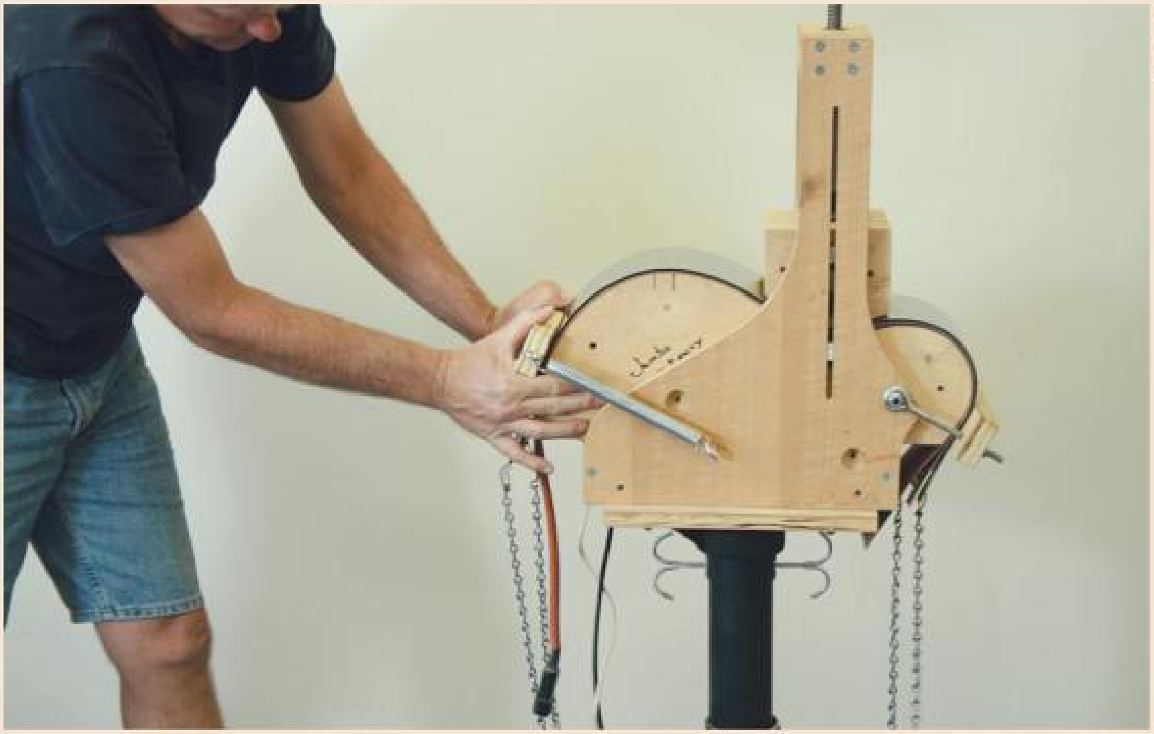
Step 1. Spray both the top and bottom surfaces of the wood with water, and keep them moist for about 15 minutes. Soaking, steaming, or boiling should not be necessary.



Step 2. Place the wood into the machine, making sure to line up the tape with the spot that will be the waist of the guitar. The machine has a screw mechanism that forces the wood down into the waist. The block on the end of the screw is the same shape as the guitar's outside.



Step 3. To bend the sides, a block of wood bolted to the sides of the machine smoothly slides over the stainless-steel blanket until it reaches the end of the curve.

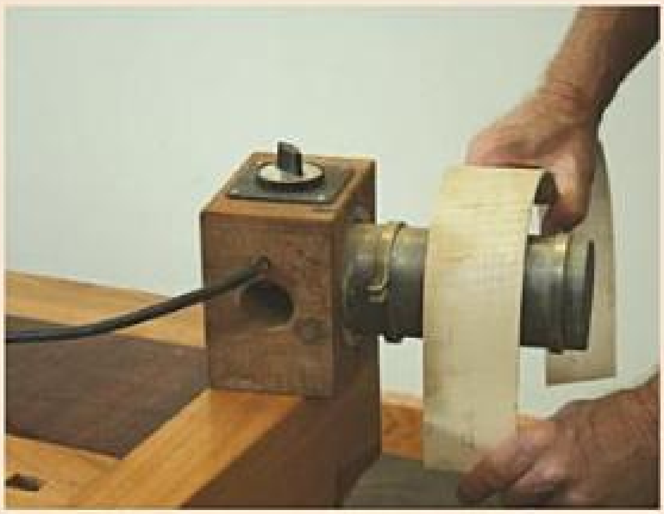


Step 4. Repeat the process to bend the guitar's bottom curve.

Step 5. Turn off the heat and allow the wood to cool. This machine has a rheostat attached to control the heat level.

STEP-BY-STEP: Bending Guitar Sides with a Bending Iron and a Form

An inside or an outside solid form can be created using the techniques described in Chapter 4, "Materials and Techniques for Bending Forms," on page 41. As is the case with any bending project, you will need an accurate drawing of the curve to use when making the form. Full-size drawings for making musical instruments can be purchased from suppliers of instrument-making materials. Any of the bending irons described in this chapter can be used in conjunction with the form. The manufactured bending iron shown here is available from tool and musical instrument suppliers.



Step 1. To make a guitar side using a bending iron, soak the wood in warm water, and then bend it around the iron.

Step 2. Bend the wood a little at a time, taking it back and forth from the iron to the form to check the curve. The wood can be remoistened with a spray bottle as you work, if necessary.

Step 3. When you're satisfied with the curve, leave the sides in the form until they're ready to use. The top and bottom of the guitar can be attached while the sides are in this form.

Step 4. The sides of the guitar also can be bent around the outside of a solid form using a bending iron the same way as in the Shaker box project on page 83. The body of the guitar is then assembled separately.

Bending with Steam

A more complicated method of using heat and moisture involves steaming wood in a steam box **(Figure 5-25)** before bending it. Though this method is more complicated, it allows you to get the maximum bend from the thickest piece of wood. In this process, heat and moisture are driven deep into the wood to soften it throughout. It takes a tremendous amount of precise force to bend a thick piece of wood around a small radius without the wood cracking, splitting, or folding.

Generating Steam

There are several ways to generate the necessary steam and heat, including a teakettle **(Figure 5-26)**, a wallpaper steamer, or a can on a burner or hot plate with a tube attached to the steam box. I have used a steamer hooked up to the steam heating system of an industrial building, and I have heard of someone else using a unit that was built to generate steam for a steam room. In general, however, you do not need to generate tremendous amounts of steam. What is critically important is getting the heat in the box to more than 200°F (93°C) and as close to 212°F (100°C) as possible in order for the wood to bend properly. Generally, the larger the steam box, the greater amount of steam it will require to fill and heat it.

Figure 5-25. A steam box, such as this one made of plywood, allows you to bend thicker wood.

Figure 5-26. A teakettle is an easy way to generate steam for a steam box.

Figure 5-27. Another type of steam box can be made of PVC pipe.

Figure 5-28. A PVC steam box usually has a hole in one end for the steam pipe and a removable plug on the other end with a hole drilled for the steam to escape.

Constructing a Steam Box

The box to hold the wood as it steams also can take a variety of shapes, from a shop-made plywood box (**Figure 5-27**) to a pipe with the steam fed in from one end and the wood loaded from the other (**Figure 5-28**). What you use to construct your steam box and how you generate the steam may depend as much upon what you have on hand or what you can easily find as anything else. No matter how you construct your steam box, there are a few principles to keep in mind:

Steam needs to enter the box and flow evenly over the wood before it exits the box. A tightly sealed box could explode if enough steam pressure builds up. To avoid that scenario, I like to build the box as tight as possible and then control where the steam escapes, ensuring steam flows into the box and passes over the entire surface area of the wood before it escapes. If the steam comes in one place and quickly escapes without evenly covering the wood, there will be cold spots in the wood, which will be prone to failure during the bending process. The box shown in **Figure 5-26** has an entry for the steam in the middle and vent holes at either end. A steam box made from a metal or PVC pipe usually will have a hole in one end for the steam pipe to enter and a removable plug on the other end with a hole drilled in it for the steam to escape (**Figure 5-28**). The plug can be removed when loading and unloading the box. A rag stuffed in the end also will work very well. A word about using PVC pipe for a steam box: you will need to support the underside of the pipe to keep the heat from softening it. If it softens and is unsupported, it can sag. A 2x4 or a piece of angle iron strapped to the bottom of the PVC pipe should offer enough support. Use PVC pipe that is at least schedule-40 thickness.

A steam box should not be considerably larger than the wood being steamed, unless you are generating a large amount of steam. It is critical to keep the heat in the box as close to 212°F (100°C) as possible—so the larger the inside of the box, the more steam it will take to fill it and to keep the temperature high enough. Padding can be added around the box to help it retain more heat (**Figure 5-29**).

The wood must be suspended inside the box so the steam can easily surround it. The box shown (**Figure 5-30**) has holes drilled in the sides for dowels to run across the width of the box. Metal rods will work also, but they will have to be stainless steel to prevent them from staining the wood.

Figure 5-29. Drape a blanket over the box to help it retain heat.

Figure 5-30. Dowels are an easy way to suspend the wood inside most types of steam boxes.

STEP-BY-STEP: Making a PVC Steam Box

To make a steam box from PVC pipe, make sure you have the following tools and materials handy: a length of heavy PVC pipe about 4" (10cm) in diameter; a drill with a bit the size of your inflow hose and a ¼" (6mm) bit, a steam hose, PVC cement, three ¼" (6mm)-diameter dowels, a hammer, and a handsaw.

Step 1. Drill a hole for the steam hose in one of the end caps of the PVC pipe.

Step 2. Glue the end cap onto the PVC pipe using PVC cement. Make sure it is seated properly.

Step 3. Drill holes in the pipe for the wood-supporting dowels. There should be three sets of holes for the three dowels, drilled below the center diameter of the pipe. One set should be in the center of the length, and the others should be 3" (7.5cm) to 4" (10cm) in from each end.

Step 4. Tap the dowels through the holes drilled in the pipe using a hammer. Using the handsaw, saw off the dowels so they are flush with the pipe.

Step 5. The completed PVC steam box should look like this. Once it is loaded with wood, plug the open end with a rag.

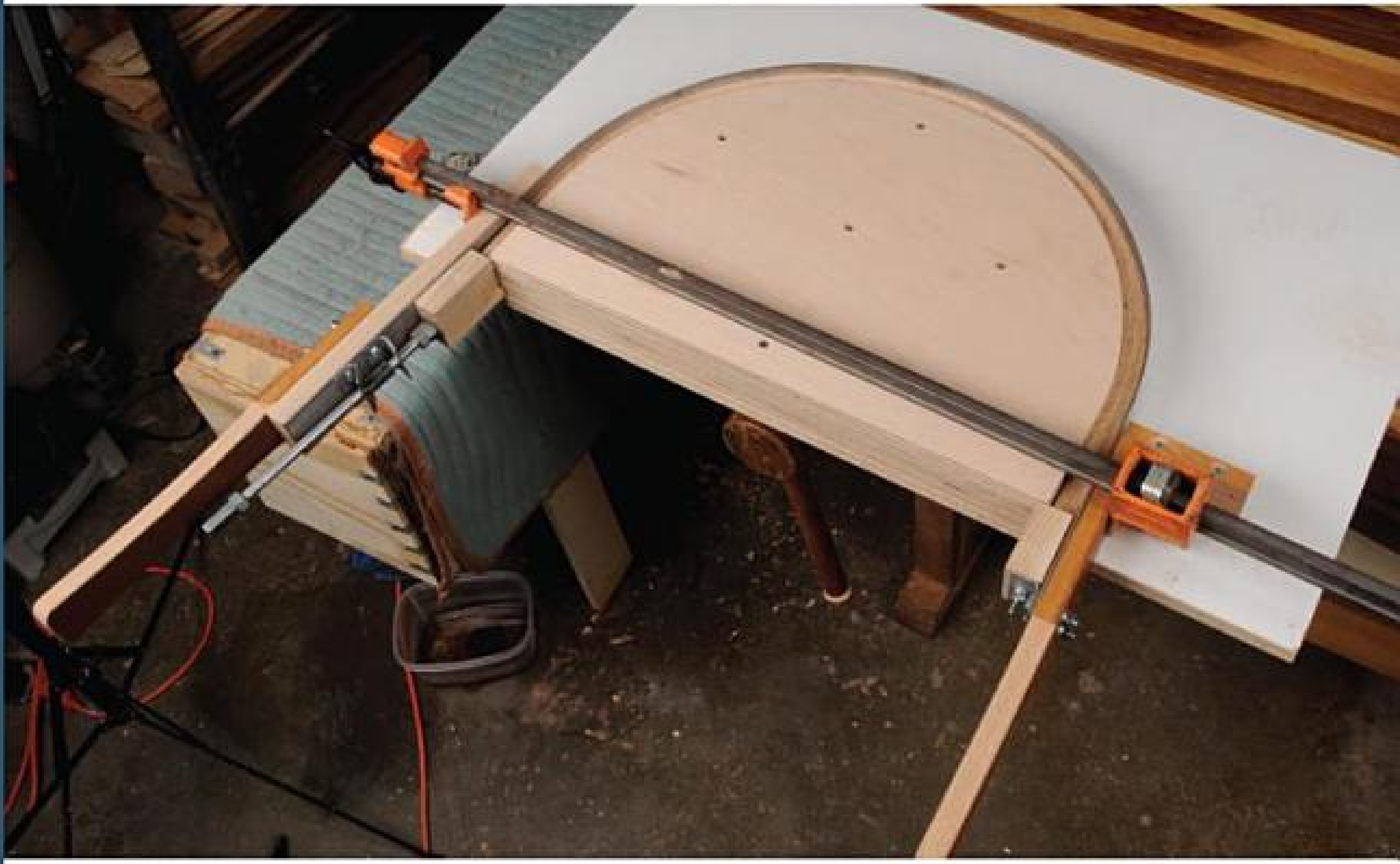


Figure 5-32. A large board under the form helps keep everything flat. This form has a cleat on the bottom that allows the form to be clamped in a vise.

Constructing a Proper Form

You also will want to give thought to how you will construct the form for steam bending. The shape for the curve is usually made from a stack of plywood or MDF, and constructed and shaped in the same manner as the Shaker box form described on page 72. Before you begin, there are some other factors to consider before you begin building a form for steam bending:

The form for steam bending needs to be sturdy. It helps to attach a cleat to the bottom of it so it can be clamped in a vise. It is also very beneficial to have a board larger than the size of the curve under the form to ensure that the curve comes out flat **(Figure 5-32)**.

Use end blocks and a compression strap to help the thick wood bend. You will need to use trial and error to determine how far from the ends to place the blocks. If they are too close to the ends of the wood to be bent, there will be too much compression, which will prevent the wood from bending all of the way around the form. Too much end pressure can cause the wood fibers on the wood's inside to fold back over on themselves, which can cause wrinkles or folds on the wood's surface. On the other hand, if the end blocks are too far away from the ends of the wood, there won't be enough end pressure to prevent the grain on the outside of the curve from splitting **(Figure 5-33)**.

STEP-BY-STEP: Sharpening a Plane Iron

▲ **Step 1**. Lap the plane sole on lapping plates. These are pieces of 1/4" plate glass with wet/dry sandpaper attached to them with two-sided tape or spray adhesive. For a detailed discussion of lapping and sandpaper, see page 48. Color the sole (bottom of the plane) with a felt marker, dribble a few drops of water on the lapping plates, and work down through the grits until the marker color disappears completely. Don't remove the blade and cap iron. Retard the blade so it doesn't protrude, but leave it in the plane to maintain normal tension, or the sole won't ever be flat.

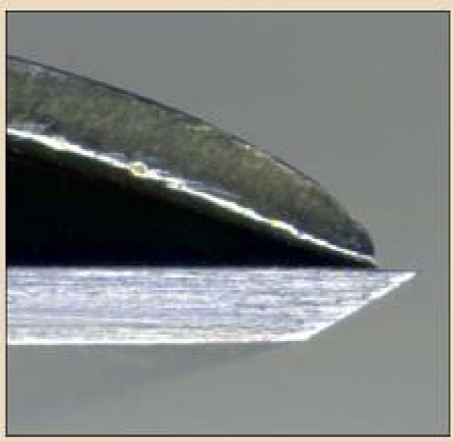
▲ **Step 2**. Flatten the back (the face with no bevel) on the lapping plates. You need to flatten only the 1/2" to 1" nearest to the cutting edge. After lapping, work down through the grits from your coarsest stone to your finest.

▲ **Step 3**. To grind the primary bevel, set a honing guide to 25 degrees and work down through the stones from coarse to medium. Move the iron around on the stone to avoid wearing grooves (see page 24).

▲ **Step 4**. Reset the guide for two more degrees to 27 degrees for softwoods, while 28 degrees is better for harder species. Repeat the honing process to create a secondary bevel. It should be about 1/8" wide. Work all the way down to a polishing water stone of at least 4000 grit, and preferably 8000 (in oilstones, a hard black Arkansas is a close equivalent).

▲ **Step 5**. Charge a stropping wheel with Flexcut Gold or a similar compound, and pass the blade quickly across it, removing the tiny burr left by very fine stones. The wheel should be running slowly, 200 to 300 rpm. You can replace this step by using a cotton buffing wheel on a bench grinder, using the same compound.

▲ **Step 6**. The cap iron and the lever cap of a plane secure the iron. Run a diamond hone across the lever cap to make sure it's perfectly flat before you place the cap iron below it. Also flatten the cap iron where it contacts the blade, using a flat stone or the lapping plate. The cap iron has to have full contact all the way across the blade, must be positioned so that it guides and breaks up shavings as they form, and must prevent shavings from being trapped between itself and the blade. Any gap whatsoever between the blade and the cap iron will jam the plane with shavings and slivers on the second or third stroke.



◀ **Step 7**. Assemble the plane with as little as possible of the iron (blade) protruding below the sole. Place the cap iron correctly before locking it in place: A good starting spot is 1/16" up from the cutting edge of the blade, and experiment from there for perfect results. The first mistake that new woodworkers make with planes is having the iron protrude too far, forcing the plane to take a thick slice of wood instead of a shaving. By starting with almost no contact and slowly increasing the exposure, you can reach a spot where the plane takes thin, uniform ribbons with virtually no resistance.

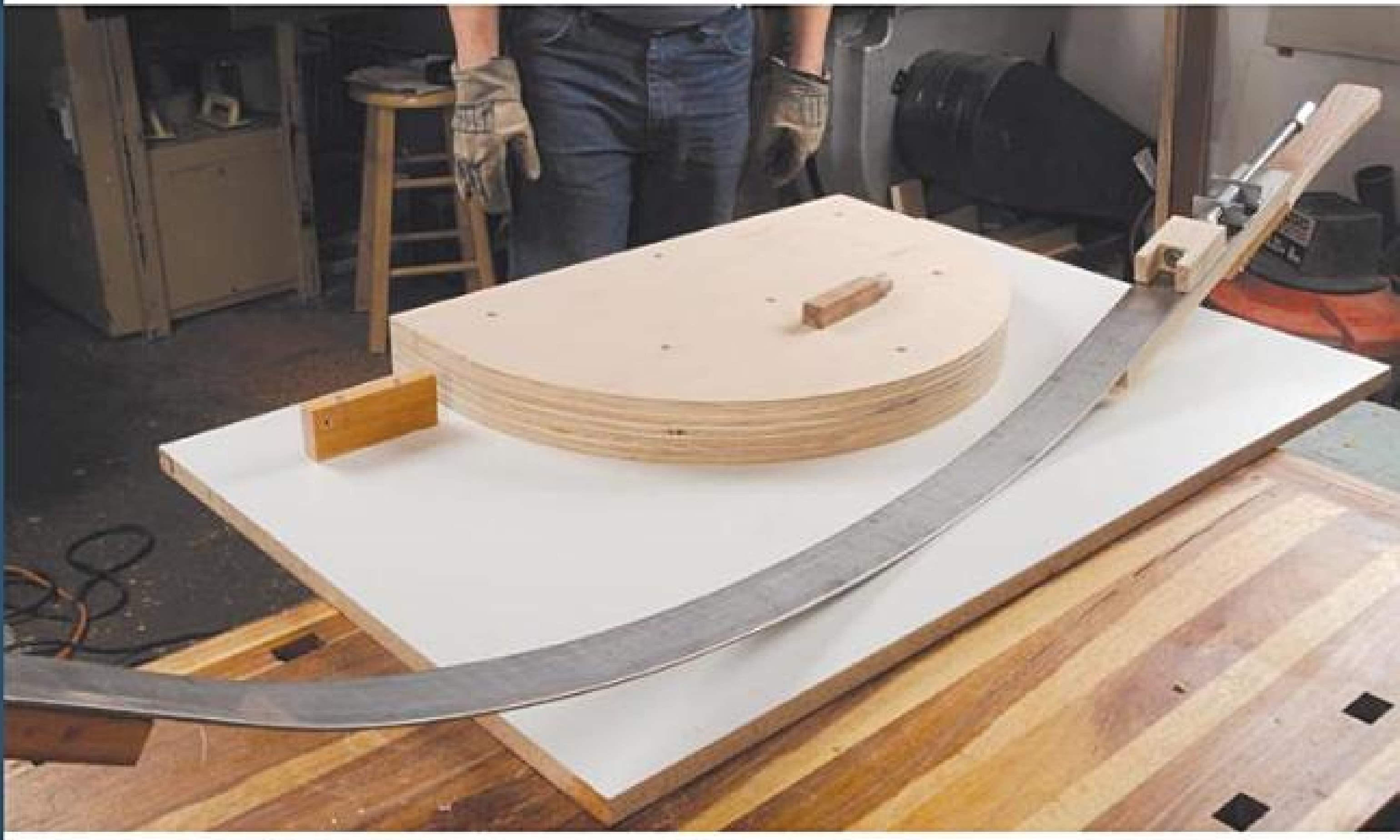


Figure 5-36. Have your form set up, complete with compression strap and removable peg, and your gloves on before the wood comes out of the box.

Figure 5-37. How the form works: the removable peg at right holds the bend in place until you're able to clamp it.

Set everything up before you begin. Lay out and arrange everything you need, and plan each step because once the wood comes out of the box, you have to move fast. Before bending, clamp the form securely to a sturdy bench or table. Wear gloves because the wood will be hot **(Figure 5-36)**. Stick to your script and don't panic, just move in a deliberate manner. It is very beneficial to have a helper on hand to hold one end of the compression strap and to apply the clamp. If no one is available, a dowel or a block of wood placed at the beginning of the bend will secure one end of the strap while you pull the strap's other end around the curve's radius. After the wood has been pulled around the curve, secure it with a clamp. If you are working by yourself, another dowel can be placed at the end of the bend until you can get a bar clamp placed across the curve's arc **(Figure 5-37)**.

STEP-BY-STEP: Bending an Oak Board

In this step-by-step, I'll show you how to bend a 1" (2.5cm)-thick oak board. I'm using a plywood steam box, but any steam box will work. Before you begin this project, be sure to build your form and prepare any materials.

Step 1. Load the wood into the steam box and close and latch the box. Let the wood steam for at least 30 minutes. Make sure the temperature inside the steam box is at least 200°F (93°C) before loading the wood.

Step 2. While the wood steams, set up your work area. You should have a compression, or bending, strap with an adjustable end block, a removable peg (left), a bending form on a base plate, and heat-resistant gloves. The cleat on the bottom of the form is trapped in the bench vise.

Step 3. Open the steam box and remove the piece of wood. .

Step 4. Press the steamed wood into the compression strap. It should fit snugly between the end blocks. Start the bend by anchoring one end on the stop block.

Step 5. Pull the hot wood around the bending form. You'll need to put your whole body into the bend.

STEP-BY-STEP: Sharpening a Roughing Gouge

Step 1. Set the tool rest on the grinder to 90 degrees, and square off the end in short contacts with the stone. Repeatedly quench the tool in cool water to avoid any heat buildup.

Step 2. Set the tool rest to 45 degrees and grind a new bevel on the end. Roll the gouge back and forth, spending a hair more time on the outside edges than on the center. The rolling motion means the center of the edge is likely to spend more time in contact with the wheel than the ends, so to avoid overgrinding, speed up a little there. If have two grits of stone on your grinder, do most of the grinding on the finer one. Check the edge by looking straight at it: You are looking for an edge that doesn't reflect light (no flat spots).

Step 3. Use a shaped slip stone or 400-grit wet/dry sandpaper wrapped on a dowel (choose one that is as close to the inside diameter of the gouge as possible) to remove the burr created by grinding. Water isn't necessary, but if you do use any, make sure the gouge is completely dry before you store it.

Courtesy DMT®, Diamond Machining Technology

Step 4. Keep a coarse bench stone handy for touchups between grinding. In use, a roughing gouge usually wears down quickest in the center, while the sides hold an edge longer. A quick dressing of the center every now and then means that you won't have to stop and grind so often.

Steam Bending a Recurved Bow

One of the earliest uses for bending wood was to create a bow to shoot arrows, and a bow is still a great steam-bending project today. You can, however, boil the ends of the bow in a pot of hot water, as well. There are many types of bows from many cultures, but the construction principles are the same. The tension of the bentwood trying to straighten itself out is transferred to a string that holds the wood in tension. Even more tension is applied as the string is pulled back with the arrow. A great amount of tension is then released all at once as the arrow is fired.

Selecting Wood for a Bow

Wood selection is an important part of making a bow. The wood you choose must be strong yet flexible. Hickory and yew are two of the most commonly used woods to make bows. These woods are sturdy and possess good bending properties. A common wood used by Native Americans was Osage-orange, also known as hedge apple and horse apple for the large grapefruit-size balls that grow on it in the fall. This wood is readily available, relatively easy to bend, and strong but not overly heavy. Osage-orange is still used today for handmade bows for these same reasons and also for its beauty when finished. Coincidentally, an Osage-orange tree in my yard was badly damaged in a storm, so I will demonstrate the construction of a bow from a standing tree to finish (**Figure 5-38**). However, a bow can be made from wood obtained from a lumberyard just as easily using the processes described on page 107.

Figure 5-38. A recurved archery bow is a great project to steam-bend, but it is best if made from wood that has been split out of the log, rather than sawn, because it's essential that the grain not run out, otherwise the bow is liable to split under tension.

Figure 5-38. Osage-orange is traditional wood for bow making. This Osage-orange tree was damaged in a storm, so I was able to use it to demonstrate the entire bow-making process for this book.

Figure 5-39. If you prefer, you can cut green wood into rectangular blanks to dry.

Figure 5-40. A recurved bow bends backward on itself, giving it more power. This tillering board helps you check the bow's curve for uniformity.

Selecting Grain

As with any wood-bending project, choose material with grain that runs parallel to the surface and avoid any defects so the wood does not fail during bending. If you are cutting wood from a tree, the trunk will usually possess the straightest grain, but a large, straight limb will do, too. There are several advantages to felling your own tree. One advantage in harvesting your own lumber is the wood can be split following the grain, so the grain exactly follows the surface of the blank cut from the wood. This type of cut helps keep the grain from running out and causing possible cracks. Another advantage to felling your own lumber is you can cut boards sawn with the grain and air-dry them (**Figure 5-39**). As described in "Moisture Content" on page 27, air-dried wood has better bending properties than kiln-dried lumber.

In this case, I used the trunk of a tree that measured about 12" (30cm) in diameter. The length of a bow can vary from 5' (150cm) or 6' (180cm) for a long bow down to 4' (120cm) for a short bow. A bow can be bent just in the middle or also curved backward at the ends to add more power and speed. We'll be making the type that curves backward at the ends, which is called a recurved bow. (**Figure 5-40**).

Though cutting your own lumber gives you an advantage when it comes to grain, there is not a great advantage to using green wood for a bow before it is properly seasoned, or dried. Green wood does bend quite easily, but much of the power from a bow comes from the wood as it tries to straighten itself out after bending. Green wood tends to stay curved, which reduces the power stored in the bow. Constant use also will soften the wood, further reducing the bow's strength. Because air-dried wood has better bending qualities than kiln-dried wood, I cut the wood for my bow into rough billets and allowed the wood to dry for 1 year before bending it (**Figure 5-41**). If you are not up for the task of splitting wood, the wood can be cut into rectangular blanks on the band saw or with a handsaw.

To decrease the drying time, blanks can be cut out to nearly their finished size and shape and then air-dried for about 6 months. Either way, be sure to seal the ends with glue or tape to prevent cracking (**Figure 5-42**). A bow has a thick center part, known as the handle, with ends that taper out toward the end, which are called the limbs. The log I cut was large enough for many bows, so I made several blanks of different shapes and sizes. The dimensions given here are suggestions, but you might want to vary some of the sizes to see how that affects the speed, power, and accuracy of the bow.

Wider, thicker boards cut from green logs can also be bent, but in most cases, there seems to be no clear advantage to steam bending green boards over steaming dried wood. In fact, adding steam to green wood can oversaturate the fibers in the wood, causing them to crush on the inside of the radius as bending pressure is applied.

Figure 5-41. Because air-dried wood is better for steam bending than green wood, I cut the Osage-orange into billets and dried it for a year.

Figure 5-42. No matter what cutting method you choose, seal the ends of the wood to prevent cracking. I used glue on the Osage-orange. Even with the glue, the Osage-orange wants to crack.

STEP-BY-STEP: Harvesting Lumber for a Bow

Cutting your own lumber allows you to ensure the grain follows the wood exactly as you want it to. Here's a quick method for harvesting the lumber for a bow.

Step 1. Find a tree you can use. This Osage-orange tree in my yard was damaged in a storm.

Step 2. Look for a natural crack in the log to begin the split.

Step 3. Use a wedge to begin splitting the wood.

Step 4. Split down the length of the log. The photo shows the log split in half.

Step 5. Split smaller billets off for bow blanks. Seal the ends with glue to prevent checking during storage.

Step 6. Split or saw the bow blank along one annual ring, which will be the front of the bow.

Step 7. These blanks are cut in various stages for drying, from a billet (left) to bow blanks (right). Any form is suitable for drying, but the more material removed, the shorter the drying time.

Step 8. This is a sawn plank of Osage-orange, with two bow blanks split out of it. The thick portion will be the handle of the bow.

Figure 5-43. The wood for the bow should steam for only about 20 minutes.

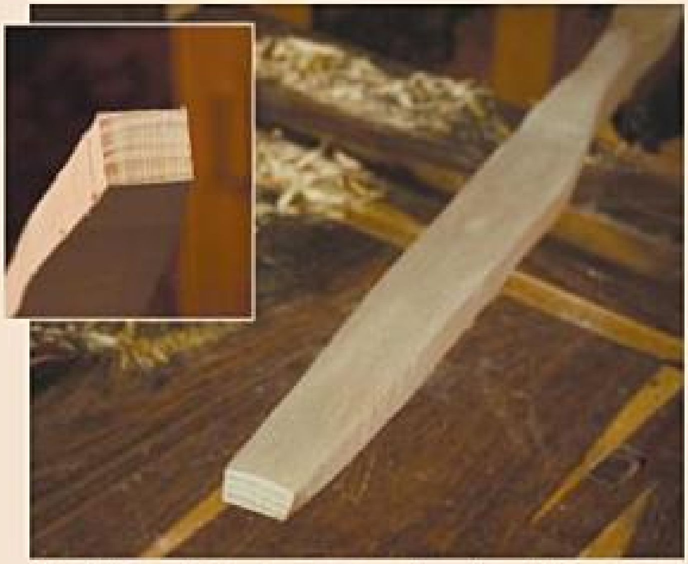
Bending the Bow

There are several ways to bend the ends of a recurved bow. You'll need enough steam and heat to sufficiently soften the wood before bending. This can be supplied by one of the steam boxes detailed in this chapter, or the ends of the bow can be boiled in a pot of water. Wood this thin should only need to be steamed for about 20 minutes (**Figure 5-43**). As with any steam-bending process, the heat will need to be above 200°F (93°C) the entire time in order for the wood to bend properly. Make sure to overbend the ends a little to compensate for springback.

The bow is shaped to its final size using a belt sander, spokeshave, a rasp, or sandpaper before bending. The limbs of a good bow should be thicker toward the center and taper out at the ends. Just as important as a pleasing shape is the ability of the bow to bend evenly. Test the bend by placing the bow into a bar clamp or tying it with string and applying a little pressure. There should be a nice, uniform curve throughout the length, with more curving toward the ends and less in the center where the wood is thickest. Make any adjustments with sandpaper until the bend is uniform. When you have a smooth, pleasing, and even shape, the ends are ready to be bent.

DEMONSTRATION PROJECT: Making the Recurved Bow

As you complete the process, take note of the times and temperatures for the bend on the first side, and try to duplicate them for the bend on the other end of the bow to maintain consistency.



Step 1. To create the strongest bow, shape the outside surface right along one annual ring without penetrating through to the next ring. Then, shape the inside of the bow using the outside surface as a reference, penetrating the annual rings on the inside as needed to get a pleasing tapered shape.

Step 2. The roughed-out blank can be shaped using a variety of hand tools, including a spokeshave, a rasp, coarse sandpaper, or a stationary belt sander.

Step 3. To maintain consistency, use calipers to measure the thickness of each limb. This bow is less than 5' (150cm) in total length. A long bow can be as long as 6' (180cm). The limbs are ⅜" (10mm) thick at the tips, about ¾" (20mm) thick near the handle, ⅝" (16mm) wide at the tips, 1½" (3.8cm) wide at the widest point in the center of the limb, and about 1" (2.5cm) wide near the handle. The handle is about 1½" (3.8cm) by 1½" (3.8cm) and at least 6" (15cm) long.

Step 4. After refining the shape of one end of the bow, trace the outline on a piece of paper, attach the copy to the other limb, and cut out the shape on the band saw. Finally, round the edges and finish shaping using hand tools.

Step 5. Shape the handle using a rasp or file and then coarse sandpaper.

Step 6. Bend the limb by hand to see if there is a pleasing, even bend. If there is a flat spot along the length, remove a little more material from the thickness until it bends evenly.

Step 7. Bend the bow in a bar clamp to see if each limb bends evenly. The limb on the right is bending slightly less, so a little more material will need to be removed near the center of the limb. Blocks are clamped to the bar clamp to prevent the bow from slipping out. Once the bend seems uniform, use sandpaper to make sure the shape is as smooth as you want.

Step 8. To prepare the first limb of the bow for bending, soften it in a PVC steam box, or boil it in a pot of water (as shown in "Bending the Laminations" on page 118).

Step 9. This form has a 12" (30cm) radius, which should work for a 4½' (135cm) to 5' (150cm) bow. The recurve should travel about one-fourth or one-third the length of each limb as measured in from the end.

Step 10. Use a block to hold the tip of the limb in place, bend the limb around the form, and then clamp it in place. Allow the curve to dry for about 2 hours before removing it from the form.

Step 11. For this test-bend, the face of the re-curve is pulled back flush to the square. There should be at least 6" (15cm) from the handle out to the vertical surface of the square. The distance will be increased when the bowstring is applied.

Step 12. Place the other end of the bow into the steamer and soften it for about 20 minutes. Bend it in the same manner as the first end. Sand and clean up the bow as necessary and cut the notches on the end for the bowstring with a Dremel tool or a file. Before applying finish, add leather or rawhide to the handle. Because you are making a bow that is not a specific length, you will need to special order bowstring. I have found it best to order a custom-made bowstring that's 4" (10cm) shorter than the relaxed length of the bow. Custom-made strings are available at most sporting goods stores.

Bending with a Microwave Oven

Another method for quickly adding heat and moisture to small pieces of wood is to use a microwave oven (**Figure 5-44**). As long as the wood and a means of keeping the wood moist can fit into the oven, this is an extremely efficient method for softening wood. Through experimentation, I have found there are several things to take into consideration when steaming wood in a microwave oven.

A microwave oven works by focusing tightly shaped radio waves on the water molecules within whatever is placed inside the oven. The molecules become highly agitated and as a result, they give off heat. A dried piece of wood will heat up quickly when placed into the oven because it still contains enough water molecules to create heat. When the wood is removed, it is very hot, but it dries out very quickly because the water molecules have broken down and so they easily evaporate. This process actually makes a microwave oven a good tool for drying small pieces of wood for turning and other small projects—but only if the moisture content is lowered slowly enough to prevent cracking.

To make the microwave useful for bending, you need to add some moisture to the equation, just as you do when steaming wood. There only needs to be enough water present to surround the wood. Any extra water will just slow down the process. Wood can be wrapped in a soaking-wet rag (**Figure 5-45**) or placed in a shallow microwave-safe bowl with just enough water to

Figure 5-44. The microwave oven can be useful for drying and steaming small pieces of wood.

cover the wood **(Figure 5-46)**. There is no set time for heating wood in a microwave, so a little trial and error will be needed. Usually 5 to 10 minutes will do the trick. Keep a close eye on the progress, because if all of the water evaporates and the wood continues to heat, it could catch on fire.

Another thing I discovered in my experiments is green wood has enough moisture in it to be heated without additional water. However, overheating it will dry the wood too much.

Whatever method you use to heat the wood in a microwave, you will need to use a good form and a compression strap, like the ones described throughout this chapter, for the wood to bend properly.

Figure 5-46. Another method is to cover the wood in water in a shallow, microwave-safe dish.

Figure 5-45. Wrapping wood in a damp towel is one way to steam it in the microwave.

CHAPTER 6

Solid-Wood Bent Laminations

Working with bent laminations means taking a thick piece of solid wood, cutting it into thin strips that can easily bend, and then gluing the strips back together in a curved form (**Figure 6-1**). If you've completed the Shaker box on page 71, you have already worked with a single bent layer. In this chapter, we'll build on what you learned when you constructed the Shaker box and also add some entirely new techniques.

Figure 6-1. Solid-wood bent laminations provide a strong curved piece. Shown here is a laminated walnut drawer front, just out of the form that made it.

Why Use Solid-Wood Bent Laminations?

There are several advantages to bending wood this way. For many small projects, using solid-wood bent laminations is usually faster and more reliable than steaming the wood. With bent lamination, there usually is relatively little springback, the failure rate is lower than with steam bending, and the tools needed to create the laminations are probably already in your shop. Also, solid-wood bent laminations have tremendous strength due to the large amount of glue surface they contain. To bend laminations to a small radius, thin strips of wood can be soaked, steamed, or boiled, then bent to the desired radius, and allowed to dry. Finally, the layers can be glued together in a curved form.

The main disadvantages of bent laminations are the appearance of glue lines, particularly in light-colored woods; the waste of material when sawing; the added labor and width limitations imposed by your sawing and planing equipment. When layers are kept in the order they were originally cut, the glue lines can all but disappear in dark-colored woods (**Figure 6-3**). Sometimes glue lines can create a decorative effect in light-colored woods.

Figure 6-2. The demonstration cabinet is made of walnut and cherry. Its legs consist of tapered laminations bent and clamped on a one-part form. The drawer rails and drawer front, and the edge banding on the cabinet top and bottom panels, are laminations bent in a two-part form closed with clamps. The door panels consist of cherry veneer on both sides of a piece of ¼" (6mm) plywood, bent on a one-piece form inside a vacuum bag. The door and drawer pulls are not bent, but sawn from turnings.

Wood-Bending TERMS

Backing board, or backer board. A board placed under a thin strip of wood as it is passed through a planer.

Cantilever. A piece of wood attached to the fixed side of a form that extends out over the movable side to keep it from rising up.

Kerf. The width left by the saw blade as it cuts through wood.

Registration marks. Marks placed on a piece of wood before it is cut up that allow the individual pieces to be put back together in their original arrangement.

Sled. A sliding table or box that holds a piece of wood at a certain angle as it is being cut or shaped on a machine.

Stair stringer. A support that runs the length of a stairway and holds all of the steps in place.

Teeth per inch (TPI). A number signifying how many teeth per inch a blade has. Fewer teeth per inch typically means easier sawdust removal and less burning of the wood.

Figure 6-3. Glue lines can all but disappear in dark-colored woods.

Figure 6-4. Curved staircases usually are supported by a carriage of curved stringers made by clamping layers of wood onto a form of studs, as shown in **Figure 6-19**. Curved handrails can be made in the same way, though they are also made by band-sawing sections from solid wood.

I have found that after considering the kerf of the saw and material removed by the planer or sander to smooth out the surfaces, up to 50% of the wood can end up as waste, depending on the laminates' thickness. It can take a lot of time to make many laminations for multiple pieces of the same shape, so steam bending may be a good alternative when making many identical parts. For making just a few pieces, though, bent lamination can be an efficient method to create a variety of shapes. Laminations can also be tapered to create bent shapes that vary in thickness, without cutting through glue lines.

Common Uses for Bent Laminations

Solid-wood bent laminations are commonly used to make furniture parts and cabinets and in architectural millwork applications. Architectural applications include arched doorways and windows, stair stringers, stair rails, and curved moldings. Many architectural parts can be fabricated using the techniques described in this chapter and then fed through a shaper or a router table to achieve the desired profile. Solid-wood laminations are also common in boatbuilding (**Figure 6-4**).

Figure 6-5. This one-part form is sturdy and has holes for the clamps to keep them square against the surface of the curve all the way around. Notice the strips under the form, which help control glue squeeze-out. This form makes compound-curved blanks for the legs of the demonstration cabinet.

Figure 6-6. This two-part form presses laminations together between the top and bottom pieces.

Figure 6-7. A one-part vacuum press form is sturdy and is used inside a vacuum bag for even pressure.

Forms for Solid Wood Bent Laminations

For solid wood bent laminations, you can use a one-part form **(Figure 6-5)**, a two-part form **(Figure 6-6)**, or a one-part vacuum press form **(Figure 6-7)**, all of which are described in the "Form Building" section on page 46. Remember, most bent lamination projects require a sturdy form that allows for placement of many clamps, unless you are using the vacuum press form or a two-part form.

All of the forms can be made of plywood or MDF, stacked to about ½" (12mm) over the desired width of the lamination. You'll need to have your full-size pattern, a saw, a drill, and a sander of some kind to cut, stack, and shape the layers of the forms.

With the one-part form, be sure you have enough clamps to ensure there are no gaps between the laminations. With the two-part form, making sure the inside and outside radii match the curve exactly will help prevent any gaps between the layers. If you are using a vacuum press, follow the steps on page 48 to make sure your bag is fitted properly and without leaks. This will ensure uniform pressure and no gaps in the laminations.

In any case, remember to attach the finished form to a larger sheet of plywood and place a series of ¼"-to-½" (6mm-to-12mm)-thick strips that are about 3"-to-4" (7.5cm-to-10cm) long perpendicular to the curve. The laminations will rest on the strips, and extra glue can flow out between them. Wax your form before use so you don't glue the lamination to the form.

Figure 6-8. Laminations need to be longer than the finished part because the laminations on the outside of the radius have farther to travel than the inside laminations. The extra length allows you to cut the laminations to a straight end after bending.

Choosing the Proper Amount of Wood

To make bent laminations, you may need to start with a piece of wood that is about twice the thickness of the final piece, because of the waste involved with sawing and smoothing each layer. However, the amount of waste will depend on the radius of the curve and the species of wood to be bent. For a larger radius, the laminations can be cut thicker, resulting in less waste. Wood that bends easier can be cut thicker than woods that do not, which will reduce waste. Please refer to the table on page 24 for a description of the bending properties of various types of wood. Remember to choose wood with grain that travels as close to parallel to the surface as possible to prevent splitting.

Just as the curve of the form needs to have extra length, the laminations also need extra length because laminations on the outside of the radius have farther to travel than laminations on the inside. You'll notice the ends of the curve will be stepped, with longer steps on the inside of the curve and shorter steps on the outside (**Figure 6-8**). To account for this and for any uneven slipping of the layers, the length of the laminates for most curves should have an extra ½"-to-1" (12mm-to-2.5cm) of material on each end. This extra will be cut off later. Also, because the layers may slide up and down, the laminates should be made at least ⅛" (3mm) wider on each side. They can be trimmed clean after the glue has set.

Test Bending the Laminations

You will want to test some pieces both before you cut the actual laminations and after you have cut them. Experiment with the wood you have to see how it bends by cutting several strips to the proper length and width of your project at various thicknesses. Next, try hand bending each of them around the form. A laminate of the proper thickness should bend around or inside the form without a huge amount of force and without cracking. There is a balance because the thinner the laminates, the easier they will bend and the less springback that will result, however more layers will need to be cut and more glue lines will be visible. Any species will bend to smaller radius if it's first soaked in hot water, steamed, or boiled before you bend it around the form. Allow the wood to dry before gluing it and bending it around the form (**Figure 6-9**).

Figure 6-9. Pre-bending strips by boiling them in hot water and then bending them around the form and allowing them to dry helps them bend to a smaller radius.

Once you have cut the actual laminations for your project and before gluing them up, test bend all of them around the form to make sure none split. For curves with a tight radius, you may want to make an extra lamination or two to replace any that split during the trial run. The glue's moisture can help some thinner laminations bend easier, but it's not a reliable way to get more bend out of a piece of wood. You won't really know what to expect until the glue is already on and the wood is in the form. A more reliable way to get more bend out of thin laminations is to soak them in warm water, steam or boil them before pre-bending them around the form, and allowing them to dry before applying glue. Ammonia can be added to the water to help the wood bend more easily, but it may interfere with the adhesion of the glue. Some experimentation will be necessary before trying this on a final project.

In the steam-bending section of this book on page 91, there is a detailed discussion of the importance of using a bending strap when steaming or boiling wood. When steaming, heating, or boiling strips of wood 3⁄16" (5mm) and under to a medium radius, there may not be enough tension present for the grain to split, so you may not need to use a strap. You will need to experiment with the particular wood you plan to use for a specific application. For the demonstration project detailed in this book, I was able to soften up the thick end of the tapered laminations by boiling them just long enough so they could be formed around the curve without using a bending strap.

Cutting Laminations

In any woodworking operation, there is more than one way to get the job done, and there are pros and cons for each. How to cut laminations from a thick piece of wood can depend on the tools at hand, the thickness and width of the laminations, and the time and materials budget.

Before you begin cutting, there are a few things you'll need to do. If you want the grain of the laminations to match up after they are glued back together, make a series of registration marks on the end of the wood to be cut (**Figure 6-10**). A triangle shape and an irregular X are good choices because they can only be put back together when the layers are stacked in the proper order. Next, square up one face and one edge of the wood on the jointer (**Figure 6-11**). The jointer should have sharp knives to prevent the grain of the wood from tearing out, and the infeed and outfeed tables need to be properly aligned to prevent removing an uneven amount of material from either end of the wood. The fence needs to be exactly 90° to the bed to prevent the wood from becoming narrower along one edge than the other. Feed the wood into the jointer so the knives will sheer off the grain cleanly and not pull it out. The first laminate is now ready to be cut on the band saw or the table saw.

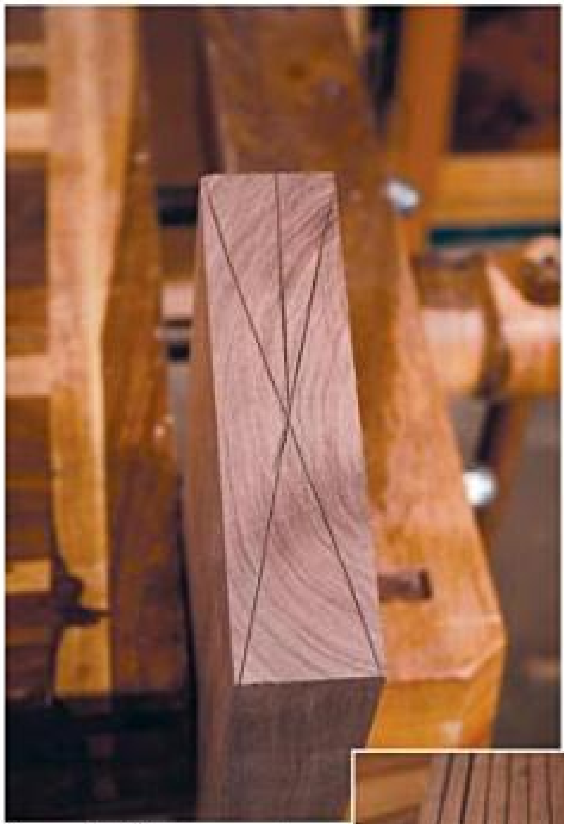


Figure 6-10. Before you cut the wood, mark a shape, such as this irregular X, on the block so that the X can only be put back together when the layers are stacked in the proper order. Putting the strips back in order can help hide glue lines.

Figure 6-11. Square one face and one edge on the jointer before cutting laminates.

Using a Band Saw

As the laminations get wider and waste becomes more of an issue, I use a band saw because it has a wider capacity than the table saw and may result in less waste due to the saw blade's kerf. The table saw will leave a ⅛" (3mm) saw kerf during the cut, and the faces of each lamination will most likely require some additional smoothing to prevent gaps from appearing between the laminations. The band saw normally leaves less of a kerf and yields more usable wood even after the surfaces have been finished.

Always install a sharp blade in the band saw before cutting any laminates. A dull blade will tend to stray from the intended cut line, burn the wood, or curve inside the cut, causing a cupped or bowed surface. A wide blade will tend to cut straighter through thick wood than a narrow blade will. Also, a blade with fewer teeth will remove sawdust more easily, reducing the chance for burning the wood. I like to use a ¾"-to-1" (20mm-to-2.5cm)-wide blade with four to six teeth per inch (TPI).

Figure 6-14. Check that the band-saw blade is square to the table so the laminates are cut evenly.

Figure 6-15. This point-style rip fence keeps a consistent distance between the fence and the blade but allows you to steer the wood back in place if the cut wanders.

The band saw rollers and guide blocks need to be adjusted properly. The owner's manual for most band saws will describe how to do this in detail. The table needs to be adjusted to 90° to the blade to prevent removing more material from one edge of the laminate than the other (**Figure 6-14**).

If the laminations are to be of a uniform thickness you may want to use a rip fence. Any rip fence needs to be adjusted properly. There are two types of rip fences that work on a band saw. The first type resembles a table saw fence and is included with most band saws. It is attached to the front and back of the table and slides back and forth in relation to the blade. The wood is fed into the saw with the fence as a guide. However, if the saw cut begins to wander away from the line, there is no way to steer it back in line because the fence is in the way. I prefer to use a point style of a fence for ripping laminates on the band saw (**Figure 6-15**). This type of fence acts as a guide to keep a consistent distance between the fence and blade, but allows you to steer the wood back in place if the cut starts to wander.

Figure 6-16.
Feed the wood into the band saw so the squared face follows the fence and the squared edge is on the table.

Cutting the First Laminate

To cut the first laminate, feed the wood into the table saw or the band saw with the face that you want to be the face of the bend along the fence and the squared edge down **(Figure 6-16)**. After the first laminate is cut, set it aside and run the just-cut surface of the wood over the jointer. This will produce one of the smooth faces of the next laminate and also provide a smooth surface to travel against the fence. After all of the laminates are cut, the second face of each needs to be smoothed out. This can be accomplished by feeding the wood through a thickness sander or a planer. It is a pretty straightforward operation on a thickness sander—just remove enough material to clean up the surface and bring each laminate to the same thickness.

To clean up the laminates using a planer, use a backing board to prevent the laminates from breaking up. Without some kind of backing, thin wood can vibrate and rise off the surface of the planer bed between the rollers, causing it to split, tear out, or just disappear up the chip chute. There are two types of backing boards that will work well for passing thin wood through a planer. One type is stationary, and the other type passes through the planer along with the wood. The stationary type of backing board is usually made of Melamine or some other type of smooth, flat material with a cleat on the underside to prevent it from passing through the planer. This type works well for laminates over ¼" (6mm) in thickness. To smooth out laminates in the planer that are ¼" (6mm) thick and under, I like to use the type of backing board that passes through the planer with the wood. This type is usually made from plywood, MDF, or another type of flat material. Fine sandpaper can be attached to the surface with spray adhesive to keep the laminates from slipping. The wood is fed into the planer with grain orientated so the knives shear off the wood fibers rather than ripping them out.

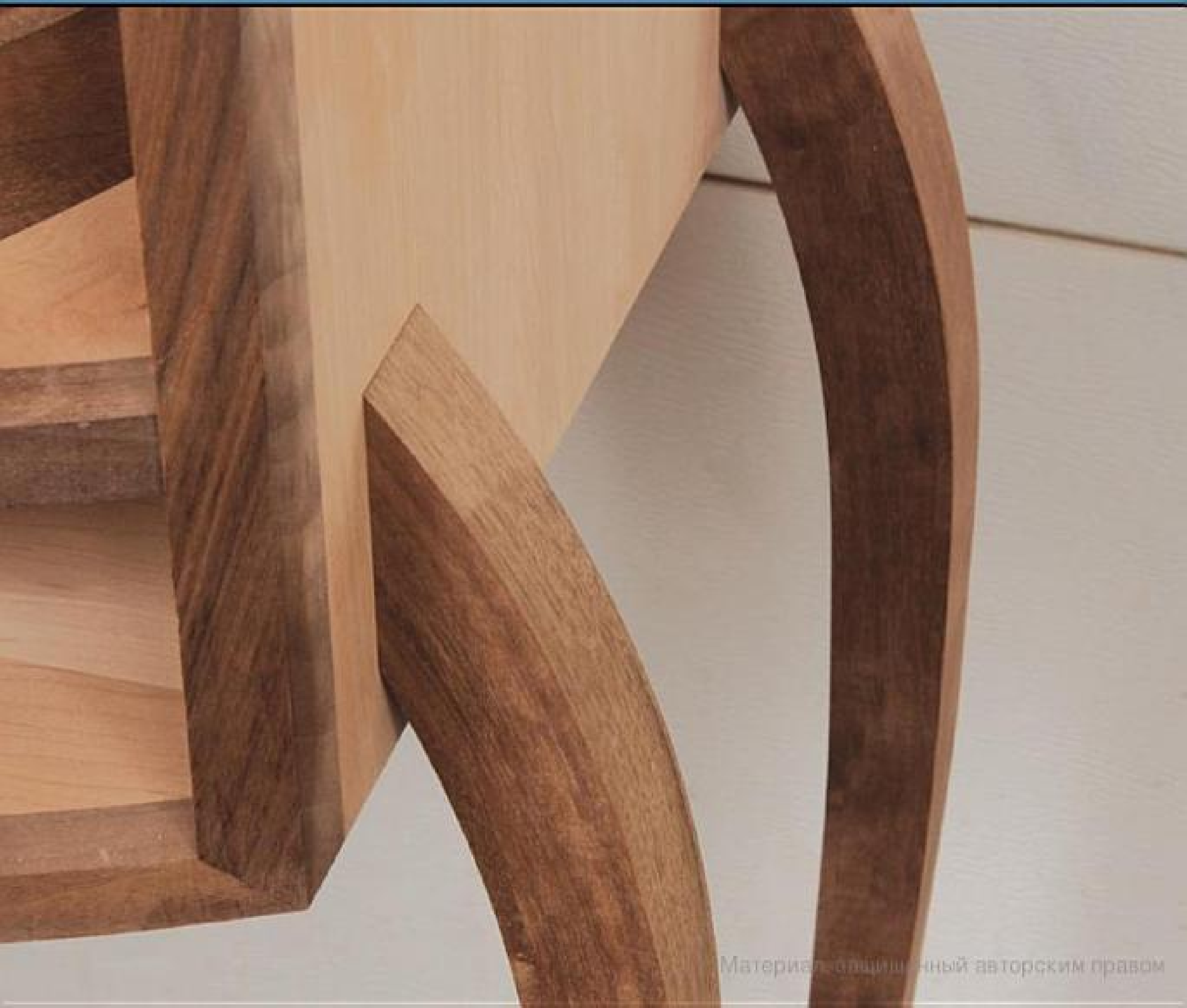


Figure 6-20. To make a curved stair stringer, construct a temporary framework of wall studs and clamp the glue-coated layers of wood to it. This process will require 100 or more clamps–unless you first wrap the stringer laminates inside a vacuum bag, as shown here. A handful of clamps pulls the laminations onto the form, then drawing the vacuum squeezes the layers of wood together inside the plastic bag.

Figure 6-19. Though often used with bent panels, as shown here, the outside technique with a vacuum press can be used for solid-wood bent laminations, as well. Two battens and four clamps hold the bagged lamination in place on the form.

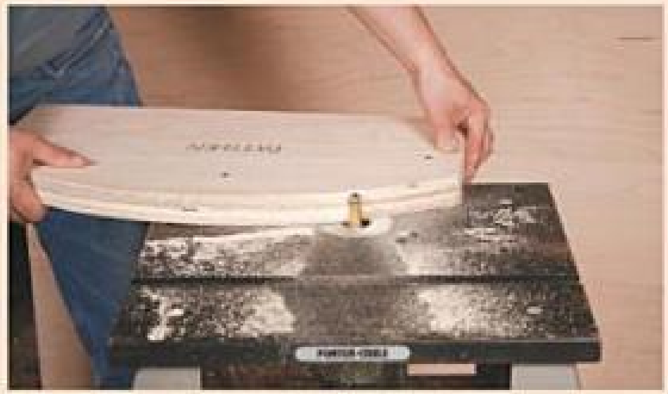
Using a Vacuum Press

The description so far has called for the use of many clamps. Clamps can be avoided altogether using a vacuum press. A detailed description for making a form and placing it into the bag, or the inside technique, is described in Chapter 3. The outside technique, in which the laminates are placed inside the vacuum bag and then bent around a form, also works well (**Figure 6-19**). Vacuum pressure is then applied to pull all of the laminates together. The form for a vacuum press can be as simple as a few sticks placed around the desired radius for the curve. A clamp is placed where each laminate intersects with a stick (**Figure 6-20**). I find myself using these two techniques more and more whether for bent plywood panels or solid wood laminations.

DEMONSTRATION PROJECT: Making Cabinet Face Frame, Rails, and Drawer Front Form

The techniques for the frames, rails, and drawer front of the cabinet follow steps similar to the legs but they will need a two-part form for bending. The solid wood laminations for the curved face frames, door rails, and drawer front should all be bent in the same two-part form so each piece will spring back equally.

Step 1. To create a thick form, make a pattern rib by attaching your original drawing to a piece of good quality plywood. For a uniform compass curve, draw it with a set of trammel points.



Step 2. Use a router or router table with a bearing-guided bit to create enough ribs to make a stack equal to the width of your lamination plus about ½" (12mm).

Step 3. Prepare a plywood base and screw a series of ½" (12mm) thick strips to it, as shown here (the ribs are beneath the plywood). Then screw the finished form to the ribbed plywood. The laminations will rest on the wood strips, and excess glue can flow out between the strips.

Step 4. Attach guide strips of wood to the top of the form to align its two parts and keep them from swimming around. Screw two strips to one part of the form, and two strips to the other. These strips will also keep the free-sliding side of the form from rising up as you apply clamping pressure.

Cutting the Laminations

A little experimentation may be required to determine the exact radius of the curve and the thickness of the laminations depending on the type of wood you choose. For this project, I used kiln-dried walnut sawed from a single 1½" (3.8cm) thick board. Each lamination is 36" (91cm) long and ¼" (6mm) thick on one end and 3/32" (2mm) thick on the other. The finished curve contains seven layers and will be about 1 9/16" (4cm) thick at the top and ¾" (20mm) thick at the bottom. The legs are 2" (5cm) wide.

It is always a good idea to cut a couple of extra laminates in case there is any split in the planer. They also can be used to test the bending radius of the curve, and they can be used as cauls when clamping.

The cuts will taper the board down considerably so you may be able to marry two legs into a narrower board or work around any knots or wavy grain. Because the grain needs to travel parallel to the surface of the laminations, I have found I need to hand select any wood for bending instead of ordering it unseen.

Making a Sled

Once you have determined the thicknesses you need, you'll need to make a sled to achieve the taper. There are two ways to create a sled for passing laminates at an angle through a planer or a thickness sander.

One type of sled consists of a flat board on the bottom, a tapered board in the center, and another flat board on top. Make the tapered board by ripping it on the band saw and then finishing it on the jointer or with a sander. A little fine sandpaper glued to the top surface of the ramp can help keep each laminate from sliding back as it passes through the planer or thickness sander. The entire jig is run through the planer or sander with the higher end first and at a slight angle to reduce tear-out (**Figure 6-24**). To make a lamination that is thicker in the center, make a sled that is concave in the center. When the sled passes through, less material will be removed from the center as the pressure of the sander or planer pushes the wood down in the center.

The sled for the demonstration project is made from one piece of wood and produces laminates that are ¼" (6mm) thick on one end and 3⁄32" (2mm) thick on the other end. To accomplish this, the sled will need to be 5⁄32" (4mm) higher on one end than the other (the difference between the two). I made a sled from a piece of 2" (5cm) by 2" (5cm) wood with a cleat on the end to prevent the laminate from slipping. The wood for any sled will need to be square or the laminates could end up wider along one edge than the other, an error that will be magnified over multiple laminates.

To create the sled, simply draw a line along the length of the sled at the proper angle, measuring up from the bottom of the board. Next, cut just outside the line using a band saw or a handsaw. Then, smooth the edge to the line using the jointer or by sanding. Finally, attach the end block to the low end of the sled. It should not rise more than ⅛" (3mm) from the surface to keep it well below the knives as it passes though the planer.

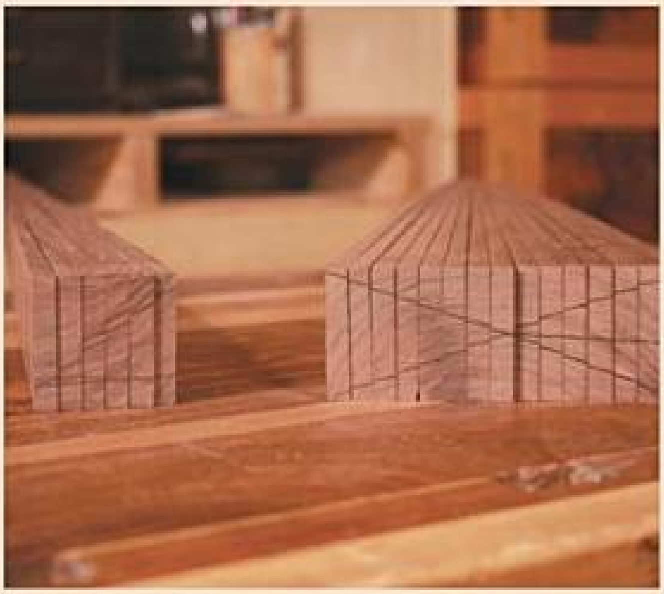
Figure 6-24. A tapered sled is run through a planer with the higher end first and at a slight angle to reduce tear-out.

Gluing and Bending the Laminations

Once the laminations are cut and smooth, they are ready to be glued together. The best adhesive for solid wood lamination is one that will dry very hard to prevent the curve from relaxing, or springing back. For the past several decades, urea formaldehyde glue has been the best choice. This type of glue allows plenty of open time, and it sets very hard. Most PVA glues just won't set hard enough to prevent springback. Titebond III, a relatively new arrival on the market, dries hard enough to prevent springback in most cases, allows enough working time for most lamination projects, and resists water.

DEMONSTRATION PROJECT: Cutting and Smoothing the Leg Laminations

Because these laminations are tapered and they need to be kept in order, it will be difficult to use a rip fence even if you combine it with a taper cutting jig. This is because the thick end of the lamination will have to come from the same end of the board for the grain to continue to match up. I have found the best way around this is to cut the laminations on the band saw without using a rip fence.



Step 1. The laminations are tapered, so you should plan on using about 3½" (9cm) of material for the thick end and about 2" (5cm) of width for the narrow end. Mark the end of the wood so you can be sure to get the strips back in their original order, for the best figure match.

Step 2. Determine the difference in thickness from one end of each laminate to the other use—for this leg it's about 5/32" (4mm). Make a sloping sled out of plywood, MDF, or solid wood that is a little longer than the laminates, and screw a stop block to the low end, which will be trailing when the sled passes through the thickness planer.

Step 3. Test-bend the first lamination on the bending form, to be sure it will be able to follow the curve without breaking, then as a fail-safe, test-bend the whole stack, as shown here. You can always plane the laminations a little thinner, and add one more if necessary.

Step 4. Once you have made one tapered lamination, use it as a pattern to lay out and saw the rest of them. If you use a marking gauge, as shown here, the thick end of the pattern will be used to mark the thin end of each new piece.

Step 5. Be sure the thick end of the lamination is always cut from the end of the board with the registration marks. This will keep the grain consistent and the registration marks visible throughout the process. Once you get started, the sequence is to mark a lamination, cut it on the band saw without using a rip fence and set it aside.

Step 6. Run the face of the board over the jointer to smooth the first face of the new lamination and mark the new lamination using the pattern lamination and a marking gauge then cut the next lamination.

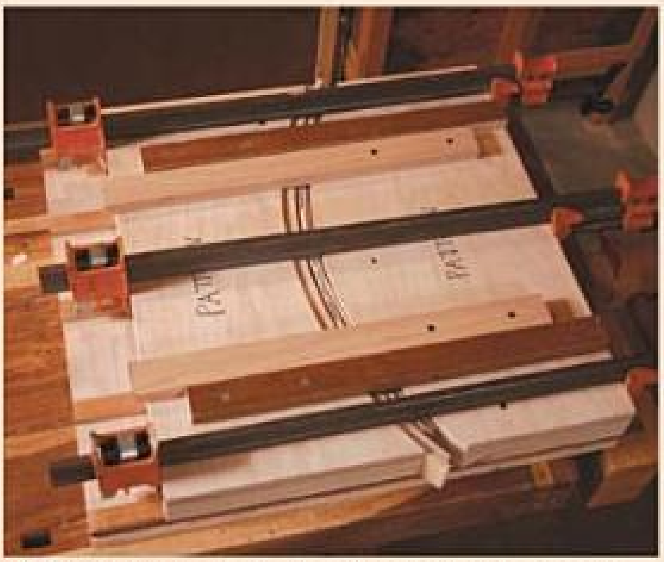
DEMONSTRATION PROJECT: Bending the Face Frame, Rail, and Drawer Front Laminations

The solid wood laminations for the curved face frames, door rails, and drawer front all were bent in the same form so each piece will spring back equally. It also helps greatly to rip all of the laminations from the same 2" (5cm)-thick board, use the same glue, and leave each curve clamped overnight. To use the same form for all of the pieces that make up the front of the cabinet, cauls of the same thickness as the door rail and face frames are placed on the inside or outside radius of the curve to account for the differences in the radii of the face frame, door rail, and drawer front.

Step 1. Apply wax to the form to prevent the glue from sticking and to allow the form to slide more easily.

Step 2. Use the end marks as a reference and stack the laminations together. Take them off the stack one by one and roll the glue on both inside faces of each layer. Then, stack them back together in order.

Step 3. To make the curved door rails, place the two ⅜" (10mm) blankets on the inside of form. This will create the proper radius for the door to fit over the frame. The blankets are on the outside of the form to create the proper radius for the curved face frame. Use bar clamps to draw the form closed.



Step 4. Allow the laminations to set overnight in the clamps to prevent springback. Then, proceed to page 153 for "Assembling the Cabinet."

CHAPTER 7

Bent Panels

Panels made using any of the techniques in this chapter can have inlayed or matched veneers applied to their surface to create beautiful designs. Applications for bent panels include cabinet doors, drawer fronts, architectural panels, legs, and sides for various furniture projects (**Figure 7-1**).

Figure 7-1.
Bent panels, such as the one being vacuum-pressed here, are commonly used for making curved doors.

How Curved Panels Are Created

In many cases when making a bent panel, you are, in essence, making your own plywood in a form, using several layers of wood or laminates. The panels are strong because they employ the same principle of cross-grain lamination as plywood. In cross-grain lamination, panels derive their strength from layers of wood glued together with the grain direction of each layer opposed to the grain direction of the previous layer **(Figure 7-2)**. Not only are the layers locked together so they cannot move, but they gain strength from the large glue surface, which makes these panels stronger than solid wood. Laminating the layers into a curved form is referred to as bent-panel lamination.

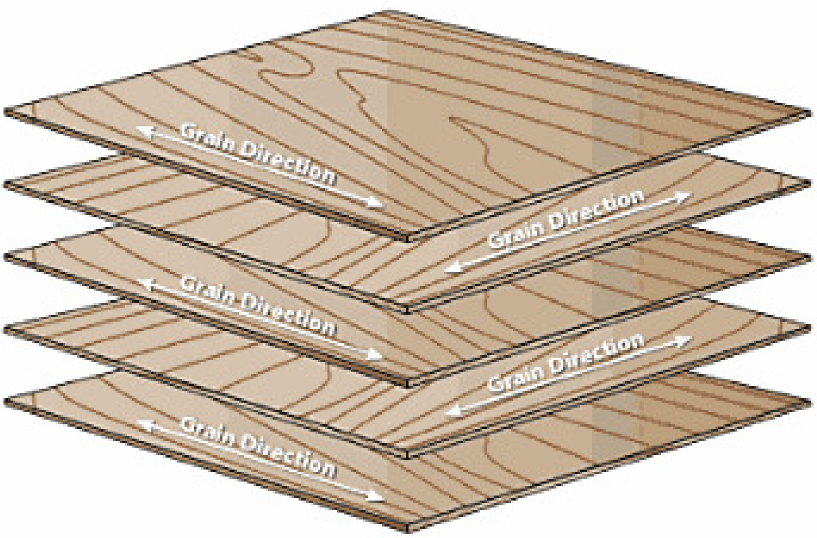


Figure 7-2. Panels derive strength from cross-grain lamination, in which layers are glued together with the grain direction of each layer opposed to the grain direction of the previous layer.

Wood-Bending TERMS

Crosscut. To cut wood across the grain.

Cross-grain lamination, or crossband lamination. Layers of wood glued together with the grain direction of each layer opposed to the grain direction of the previous layer.

Following bit. A router bit that cuts a piece to the shape of a pattern by means of a bearing that rides on the edge of the pattern.

Inlaid veneers. A veneer made by placing one veneer over another, cutting through both, and then placing the top veneer into the hole left in the bottom veneer.

Kerf-cut panel. A panel created by partially cutting through one side of the panel in a pattern of parallel lines to allow the panel to bend easily while the remaining material gives the panel structural integrity.

Matched veneers. A veneer made by slicing wood into thin layers and then opening two sequential sheets like a book to create a mirror image.

Platen. A flat sheet of Melamine with a grid of channels for the air to flow from a vacuum bag.

Rail. The horizontal member of a frame that fits in between the two vertical members, which are known as stiles.

Resaw. Saw thinner boards from a thicker board.

Rip. To cut wood with the grain.

Skin. One of the smooth outer layers of a bent panel that covers the interior layers.

Stile. The vertical sides of a frame that run the entire length of the frame with horizontal rails running between them.

CHAPTER 7

Bent Panels

Panels made using any of the techniques in this chapter can have inlayed or matched veneers applied to their surface to create beautiful designs. Applications for bent panels include cabinet doors, drawer fronts, architectural panels, legs, and sides for various furniture projects (**Figure 7-1**).

Figure 7-1.
Bent panels, such as the one being vacuum-pressed here, are commonly used for making curved doors.

Figure 7-7. Crossband both the top and bottom veneers with a thin layer of material to create two flat, semirigid sheets that function as a skin.

Bending Panels with Veneer

To bend panels with veneer, there are three different methods for holding the layers in a curved shape while the glue sets. Materials suitable for the construction of bent laminated panels include plywood, MDF, and thick-cut veneers. I sometimes combine more than one of the materials within a panel to capitalize on the strengths of each. There are several considerations for choosing the right material. Remember, the material you choose must be flexible enough to bend to the desired radius without cracking. (For more information on choosing materials, see Chapter 2, "The Principles of Wood Bending," on page 16.)

The General Method for Veneered Panels

Most of the bent panels I construct have a veneered surface. Some of the patterns are quite complicated or made up of beautifully matched veneers. Except in gentle curves, the extremely thin veneers tend to buckle, wrinkle, or tear if they are bent in combination with the other laminates. I have found a two-step process that solves this problem.

The first step is to cross-band both the top and bottom veneers with a thin layer of material, which creates two flat, semirigid sheets that function as a skin that can be sanded before bending for tight curves **(Figure 7-7)**. The second step is to sandwich the rest of the layers of the lamination between the two outer layers and press them all into the curved form **(Figure 7-8)**. This two-step process ensures the surface veneer is flat and hides any slight defects between the inner layers deep inside the panel.

Figure 7-8. Then, sandwich the rest of the layers of the lamination between these two outer layers and press them all into a curved form. You can do this with all types of forms. Shown here are a two-part form in the veneer press and a one-part form inside the vacuum bag (inside technique).

Choosing the Skin Materials

Depending on the situation, several materials work well for forming the skin. MDF always works well under the surface of any veneer because it is so smooth. It may be hard to distinguish a veneered surface with an MDF substrate from solid wood, even when it is touched or knocked with your knuckle (**Figure 7-9**). MDF that is ⅛" (3mm) thick is sometimes hard to find, and it can't bend to a small radius, but it is well worth the effort to find it if you are constructing a veneer-covered curve with a relatively large radius.

For a smaller radius, ⅛" (3mm) plywood is a good choice for making the skin (**Figure 7-10**). It always should be placed with the grain direction of the face veneer perpendicular to the surface veneer. Plywood with one face surfaced with a hardwood veneer, such as maple or oak, is an excellent choice for the skin material because it will have few surface defects that can telegraph through your surface veneer. For many projects, the ⅛" (3mm)-thick plywood with cherry, maple, or oak facing will work fine for the outside skin without having to be faced with another veneer. Baltic birch and Italian poplar are also good choices for the core material if the surface is defect-free.

For a curve with a tight radius, use 1⁄16" (1.5mm)-thick veneer placed with the grain perpendicular to the face veneer to create the semirigid skin. A few species of 1⁄16" (1.5mm)-thick veneer are available from most veneer suppliers. For a curve with a tight radius, down to as little as 1" (2.5cm) to 2" (5cm), use 1⁄16" (1.5mm) veneer to make up the entire substrate.

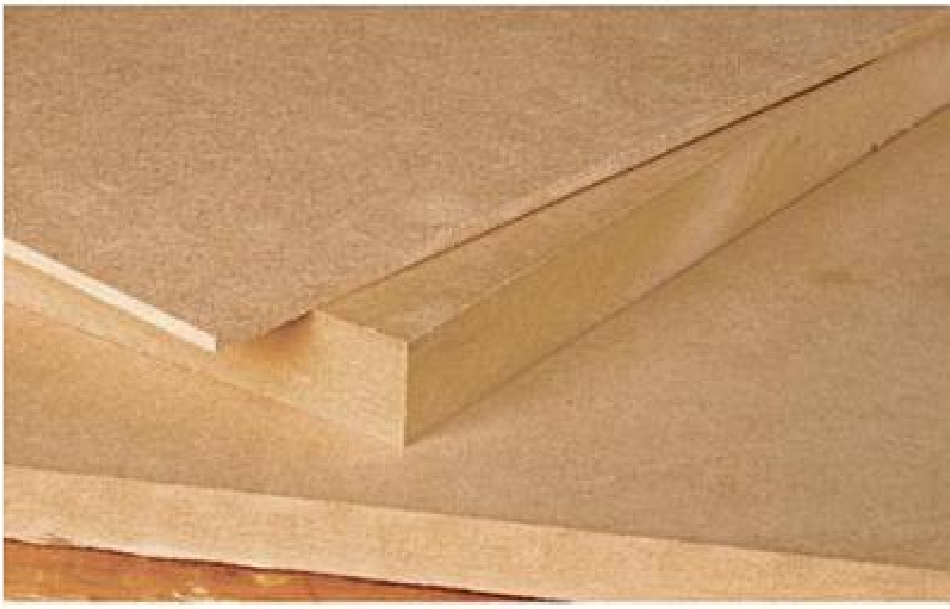


Figure 7-9. MDF is a good choice for veneered panels because it is very smooth and comes in many thicknesses.

Figure 7-10. Thin plywood is also a good choice as long as the surface is free of defects. The thick panel in front is special bending ply.

STEP-BY-STEP: Creating a Skin

Use the following process to create a two-layer skin of 1/16" (1.5mm) veneer for crossbanding. The grain direction of the skin should be opposed to that of the surface veneer. The grain direction of the inside face of the skin may end up running in the same direction as the outside layer of the core, but the forces will be equalized out from the center as long as both sides are treated the same way. Veneer this thick can be crosscut and ripped to size on a table saw.

Step 1. Crosscut pieces the same length as the veneer's width. Make enough pieces so that when they are placed side by side, they will be the length of the veneer for both sides.

Step 2. Tape the stack together, and then pass one edge over the jointer.

Step 3. To square up the pieces, rip the stack on the table saw, then plane or smooth the saw edge on the jointer.

Step 4. Lay the pieces down side by side and tape them on the back with blue painter's masking tape along the length of the joints. (This tape does not stick tight and leaves little residue.) Turn the sheet over and use this face as the glue side. Spread glue on the glue side of the 1/16" (1.5mm) veneer and place the veneer over the top.

Step 5. Place the panel in a press or vacuum bag with a layer of newsprint over the top. Then, put an MDF or plywood caul over the top. You can glue both layers at the same time by placing the second skin over the caul with a layer of newsprint and another caul.

Step 6. If you are doing both layers at the same time, spread the glue on both skins first to minimize the time the first veneer sheet is in contact with the glue before pressure is applied. After the glue has been allowed to set for 2 to 3 hours, remove the completed skins from the press and peel the tape off the back. Remove the veneer tape from the veneer face, and allow water left over from the tape removal to dry. Before proceeding to the final lamination process, sand both sides of the skins. Remove the tape from the underside, and sand that side just enough to clean it up. Finish sanding the veneer's top because it is much more difficult to sand a curved panel than a flat skin. To sand this relatively thin material, tape it down to a flat panel and sand it with a random orbit sander, starting and finishing with 220-grit sandpaper. Finally, sand by hand with the grain to remove any swirl marks left by the sander.

Step 5. Band saw the remaining ribs for the form.

Step 6. Use screws to mount the pattern piece on top of the first band-sawn rib blank.

Step 7. Use a pattern-following trim bit with a bearing in the router table to ride against the pattern and reproduce the curve in the band-sawn blank.

Step 8. Clamp the first rib onto the baseboard of the form. Then, screw the ribs onto the baseboard from the underside.

Step 9. Nail a caul of ⅜" (10mm) bending plywood onto the form ribs.

Step 10. Drill two large holes in the end rib for attaching clamps when using the form as a sled for trimming the panel. Air should be able to freely flow through the form to prevent air pockets that cause the form to collapse in the vacuum.

DEMONSTRATION PROJECT: Making Cores for the Curved Doors

Step 1. Cut two layers of ¼" (3mm) bending plywood to the size of the curved door panel. Sand off the sharp corners.

Step 2. Roll a uniform coating of glue onto both pieces of bending plywood. A small paint roller spreads the glue evenly.

Step 3. Put the panel together, gluing the pieces glued-face to glued-face. A piece of newsprint will keep glue squeeze-out from joining the plywood to the form.

Step 4. Slide the glued bending plywood onto the form inside the vacuum bag. Keep the plywood in place as the vacuum pump draws the air out of the bag.

Step 5. Atmospheric pressure forces the bending plywood to conform to the curved form.

DEMONSTRATION PROJECT: Face Veneering the Curved Door Panels

Step 1. Choose veneers for the front and back of the curved door panel. These veneers are book-matched cherry. Mark the outside face of each.

Step. 2. Take the bent-plywood panel out of the vacuum bag after it has set for several hours. Notice there is some springback. With experience, you will learn to make the curved form slightly more extreme than the finished bend, to allow for a small amount of springback.

Step 3. Pour glue on the bent-plywood core and roll it to a smooth, uniform coating.

Step 4. Carefully place the veneer on the wet glue and align it with the edges of the glued panel.

Step 5. Spray water on the veneer to compensate for the glue moisture soaking in on the other side.

Step 6. Pour and roll the glue on the panel's back in the same way as on the front. Then, add the veneer. Hold everything in place with blue painter's tape because this tape doesn't stick tight and leaves little residue.

DEMONSTRATION PROJECT: Making the Curved Doors

Step 1. Add a caul of bending plywood to protect the veneer, and insert a piece of newsprint to keep the caul from becoming accidentally glued to the veneered panel. Tape the whole assembly onto the bending form.

Step 2. Slide the form into the vacuum bag and make sure nothing has shifted. The vacuum pump will suck the panel down tight on the bending form.

Step 3. Allow the glue to set overnight. Then, remove the panel and form from the bag and strip off the protective newsprint.

Step 4. Use the bending form as a jig to secure the panel and saw the edges straight and clean on a table saw. The opposite edge can be sawed against the rip fence.

Step 5. Saw the panel ends using the crosscut box. The clean, square cherry veneer panel is ready to be fitted on the cabinet. See "Assembling the Cabinet" on page 153.

Bending Complex Panels

While complex panels (**Figure 7-12**) can be formed in a number of ways, the best way is to use the outside technique with a vacuum press, as described in Chapter 4, "Materials and Techniques for Bending Forms," on page 40. In this section, I'll show you how to make a W curve and a spiral.

Bending a W Curve

About 15 years ago, I built a large two-part form in an attempt to produce a W shape. When clamp pressure was applied from above and below, I achieved only limited success. The layers of the laminate could not slide by each other enough for them to come together tightly. Even when the layers did pull together, the material became trapped between the curve's center and bottom leg, causing the laminates and surface veneer to rip or pull apart entirely as pressure was applied. One side of the form was too large to be placed into the vacuum bag, so I gave up on the idea for a while. Years later, I discovered the outside bending technique described on page 59, and I was able to produce the W shape with relative ease.

The form for creating the shape probably doesn't need to be as sturdy as the one shown here, but I just used the original form I had created to withstand a large amount of clamp pressure in my earlier attempt (**Figure 7-13**). When using the outside technique, you'll find the forms you make will be much less substantial than this one. A simple form for making curved spiral panels using the outside technique is described in detail on page 59.

Figure 7-12. A complex W-shaped panel could be constructed in several ways.

Figure 7-13. My four-part form for creating the W is sturdier than it needs to be because it was built to withstand a large amount of clamp pressure from my earlier attempt to bend the shape using the veneer press and clamps.

Figure 7-14. Place the skins in the bag with the flexible mesh over the top. The inset shows a close-up of the flexible mesh.

Outside Techniques

To create any type of curve using the outside technique, start by making two semi-rigid skins for the two faces as described in "Creating a Skin," on page 140, and press them flat. I like to make a vacuum bag roughly the same size of the stack of laminates I plan to bend and then use the same bag for both steps of this two-step process. Either buy a bag close to the size you will need, or make one using the instructions in "Making Your Own Vacuum Bag," on page 48.

Make a platen by sawing a grid partway through a sheet of Melamine-clad fiberboard. Sand the sharp corners off the board. If you do not want to create a thick platen, sandwich the two skins to be glued between sheets of melamine or MDF that are cut just a little larger than the work piece, using flexible breather mesh instead of the melamine platen. This saves a lot of material because you can reuse the melamine or MDF later.

Place the skins in the bag with the flexible mesh over the top of the stack and press them **(Figure 7-14)**. I get good results when I use a relatively flexible adhesive, such as a PVA, for the outer skin, and glue the entire stack together within a few hours with a harder setting glue before the PVA has a chance to set up hard. To create the skins for this particular curve, I used 1/16" (1.5mm) poplar veneer to cross band the surface veneer. This creates a flexible sheet because the thicker poplar is bent across the grain, and the thin-face veneer is bent along the grain.

To construct the curve, use a harder-setting glue with a long open, or working, time, such as urea formaldehyde, or plastic resin, glue. Some people may be a concerned about using more than one type of glue within a panel. I like to capitalize on the strengths of some adhesives and, at the same time, negate the weaknesses of others by using them in combination. PVA glue will bend easily after it sets, but before it cures fully. Plastic resin glue gives you time to deal with many layers at once, but cures very hard, preventing the curve from relaxing.

The real concern when combining different adhesives and different core materials within the same panel is that everything gets treated the same, working out from the center axis, or core, of the panel. Any tension or pressure exerted by the combination of different materials will be equalized. If you need to have an even number of layers within a panel, you will not be able to have every layer arranged with the grain direction opposed to the next. In such cases, arrange the layers so only the center two layers have the grain running in the same direction or so that any layer pattern that does not alternate is repeated on both sides of the panel, which will equalize any tension out from the center.

In many cases, I have also had good luck using Titebond III, a newer form of PVA glue, to laminate all layers of a panel together. Titebond III allows 15 minutes of open time, and a panel glued with it left in the bag under pressure overnight has less springback than with any other type of PVA glue.

This panel was constructed using the two outer skins and two inner layers of ⅜" (10mm) bending plywood. The surface area of each panel is fairly large, about 24" (60cm) by 80" (200cm) and there are six faces to cover with glue, so I needed to mix up a one-gallon (approximately 4 liters) bucket of plastic resin glue, or 4 pounds (2kg). Mix the powdered glue with cool water to increase the open time and then quickly spread it with a paint roller.

For a project such as this, stack the layers with a layer of newsprint below and a layer of thick paper or thin cardboard on the top where the flexible mesh will be. The glue under the surface of the veneer could still be a little soft, or you could be working with a soft veneer and the mesh might emboss the surface of the veneer.

Place the sandwich into the bag, and seal it up to remove the air and pull the layers together. Then, allow the air to flow back into the bag by unhooking the pump. The layers should now be pulled together, but they will still be able to shift as they are forced into the form.

Apply pressure to the form to close it up. I use clamps in this case (**Figure 7-15**), and then I reattach the vacuum pump and remove the air again (**Figure 7-16**). Leave the form clamped and the vacuum pump on for 12 to 24 hours until the plastic resin glue fully sets.

Figure 7-15. Put the panel into the bag and draw the vacuum, to pull its four layers together. Then place it on the form and apply pressure with clamps.

Figure 7-16. With all four of the form pieces in place, reattach the vacuum pump and remove all of the air again.

Figure 7-17. This spiral-shaped table is made using the same techniques used to create the W table.

Making a Spiral Curve

The spiral-shaped curve **(Figure 7-17)** is made in much the same way as the W shape except the form is much simpler **(Figure 7-18)**. Make a top and bottom the to match the shape of the curve out of plywood or MDF. Then, screw the two pieces together that will make up the top and bottom. Trace the outline of the shape from the original drawing and glue it to the stack using spray adhesive.

Cut out the shape using a band saw, a jigsaw, or a handsaw. Next, sand the edges smooth using a disk sander or files and sandpaper. Drill large holes for the clamps along the edge through both pieces in areas where the edge curves the most, while the top and bottom are still stacked together.

Make the form the desired height using 2"-by-2" (5cm-by-5cm) strips placed in the areas where the panel will curve the most. The strips should line up with the drilled holes. Form the strips as needed with a hand plane to prevent lumps on the surface of the curve **(Figure 7-19)**. Cover the form with ⅜" (10mm) bending plywood, and nail it to the strips **(Figure 7-20)**. Smoothing any irregular areas or lumps using a sanding block and coarse sandpaper completes the form **(Figure 7-21)**.

Figure 7-18. Unlike the W Table, the form for the spiral table is much simpler, consisting only of a top, a bottom, strips, and a cover for the strips.

Figure 7-19. Use a hand plane to smooth the strips and prevent lumps on the surface of the curve.

Figure 7-20. Nail ⅜" (10mm) bending plywood to the strips.

Figure 7-21. Complete the form by sanding out any lumps.

To make the spiral curve, begin by making two semirigid skins as described in "Creating a Skin" on page 140. Place the sandwich of laminates into the bag with the protective paper and flexible breather mesh over the top, seal up the bag, and remove the air. Unhook the pump and clamp the one end of the bag and sandwich to one end of the form **(Figure 7-22)**.

Bend the panel around the form, and clamp boards across the panel where needed to keep the laminations against the face of the form. Do not overtighten the clamps. Too much pressure will create flat spots in the finished panel where the boards were. The clamps are meant to keep the panel against the form. Vacuum pressure pulls the layers together.

Figure 7-22. Clamp one end of the bag, and then clamp it to the form with battens, then restart the vacuum.

Figure 7-25.
The center panels *in Fault Line Wall Shelf* are an example of tapered panels.

Assembling the Cabinet

If you've been working your way through this book, then you have completed all of the bending parts of this cabinet and are now ready to put the cabinet together. Although this portion of the project does not involve wood bending, it does show you what's involved with assembling curved parts and the kind of projects you can put together using a variety of wood-bending techniques.

This project combines various wood-bending techniques to create a beautiful cabinet with curved doors, a drawer with a curved front, and tapered, bent laminated legs. You may find other ways within the pages of this book to create some of the parts that make up this cabinet. You may even want to change the design or use the techniques for another application.

When I designed this piece, I tried to create both contrast and unity of materials and shapes. I created contrast by using light and dark woods and by combining straight lines and curves. Unity was created through the use of both woods for straight lines and curves. Many of the individual parts also contain both straight lines and curves. Although this project may require a small amount of veneering to create the curved door panels (see page 146), the majority of the cabinet can be made using cherry plywood. The plywood can be laid out and carefully cut and joined so the grain of the face veneer follows around the corners of the box. To do this, lay out the panels and crosscut them very close to finished size with only the blade's thickness as waste between them. After the solid edges are applied, miter the panel's corners, removing only minimal material. Cutting the frames and panels as one unit will help ensure tight corners all around the cabinet **(Figure 7-26).**

Because the solid-wood laminations for the curved face frames, door rails, and drawer front all were bent in the same form, each piece will spring back equally. The door rails are unsupported on the ends, so for everything to line up on the cabinet's front, every radius is based on the final relaxed radius of the door rails.

Because everything is built around the radius of the relaxed curve of the door rails, it is best to make the face frames and door rails first, and then make the curve on the front of the box to fit them. (To make the legs, see "Bending the Leg Laminations," on page 132.)

Cleaning Up the Legs

After all four of the bent laminations for the legs are dried, they will need to be cleaned and squared up before the joints can be cut. The final shaping will be done after the joinery because the wood needs to remain square when cutting and aligning the parts. The easiest and safest way to clean off the glue and square up the edges is to use a stationary belt sander (**Figure 7-27**). A handheld belt sander or other hand tools also will work well to clean up the edges. A jointer is not recommended because the guard will not remain in place during the length of many curved shapes, and the glue can gum up and dull the knives. To square up a gently curved piece such as this one, the first edge is smoothed and then the curve is passed through the band saw using a rip fence to square up the second edge (**Figure 7-28**). A quick pass over the sander will clean up any band-saw marks on the edge of the leg.

After the legs have been squared up, the joints can be cut while everything is still square. A curved or tapered profile can be given to the sides of the leg after all of the joints have been fitted.

Cleaning Up and Attaching the Laminations

After all of the laminations are glued up and allowed to dry, they can be attached to the panels.

Figure 7-26. Cut the frames and panels as one unit to ensure tight corners all around the cabinet.

Figure 7-27. Clean up the curved, bent laminated legs on the stationary belt sander. I bolted a board to the side of my stationary belt sander perpendicular to the belt to act as a fence and help keep things square.

Figure 7-28. Pass the curve through the band saw using a rip fence to square up the second edge.

Figure 7-29. After the solid-wood edges are applied, the panel is mitered and cut to shape. This ensures the frames match up just right in the corners.

Figure 7-30. Use biscuits or a spline to strengthen the mitered corners of the cabinet.

Miter the Corners

When all of the facing is attached and all of the side panels are all cleaned up, the corners are ready to be mitered, and the cabinet can be assembled. The mitered corners are cut on the table saw using a crosscut sled (**Figure 7-29**). The corners are joined with biscuits (**Figure 7-30**).

I like to use a special clamping procedure for mitered boxes. I start by making four panels out of ¼" (6mm)-thick plywood just a little smaller than each side of the box. Next, I attach a 45° block along each end of the panel with glue and screws. Before gluing up the box, I clamp a panel to each side of the box. To assemble the box, I place clamps across the blocks to get pressure right on the miter. After the box is clamped and squared up, I allow it to dry for 3 to 4 hours before removing all of the clamps and panels (**Figures 7-31** and **7-32**).

Figure 7-31. Make four clamp pads and attach one to each side of the cabinet before clamping the cabinet together.

Figure 7-32. Place clamps across the corners to get even pressure on the miter joint.

Here is another trick that works every time to close up the outside of mitered corners, particularly with plywood. Immediately, after removing the clamps, use an iron to melt and reset the glue, and then force the plywood down just at the edge. This will only work with PVA glues. I used Titebond II Extend for this cabinet, but Titebond III or any other type of slower-drying PVA glues would work as well. After the glue melts and begins to harden, use a veneer hammer to force the joint closed. Finally, use a cabinet scraper and sandpaper to carefully finish the corner. Many mitered joints are tight to begin with, but this little trick can really make the whole project look perfect (**Figures 7-33** through **7-36**).

Figure 7-33. To close up any gaps on the outside of the miter, melt and reset the glue with an iron.

Figure 7-34. Gently force the gap closed with a veneer hammer.

Figure 7-35. Use a cabinet scraper and sandpaper to clean up the corner.

Figure 7-36. Once the drawer front has been bent, it should be ready to fit.

Attach the Legs

The legs can now be attached to the cabinet. Use the following sequence to make tenons on the ends of the legs. Adding tenons to the joints will give them a tremendous mechanical advantage over joints that only consist of screwing the legs to the sides of the cabinet. The grain of the wood goes from within each leg right into the side of the cabinet.

There are two efficient methods for cutting joints on a curved piece of wood. The first method is to cut the joints into the wood while the wood is still square, and the second method is to cut it after the wood has been bent. The first method works for curved shapes cut out of a piece of solid wood. During bending, wood tends to deform and change shape, so any joints that fit before bending may not fit after. In laminated bends, the laminations slide around or shift during the bending process, so the joints will need to be cut after the laminations have been bent.

DEMONSTRATION PROJECT: Making Joints in Curved Parts

The best way to cut joints on curved members is to secure the piece into a jig that matches the shape of the curve on one side and is straight on the other side to reference the cut. The simple forms described here are traced from the curved pieces with which they are to be used and then cut out on the band saw. The bent piece can be held in the jig with tape, double-sided tape, or hot glue. A more advanced type of jig with hold-down clips can be made for multiple uses. The jigs described here are meant to be used only a few times and then discarded.

Step 1. The mortise and tenon should fit together tightly. Cut mortises on the side panels for the tenons on the bent legs.

Step 2. Use a plunge router with stops to cut the mortises first, and then fit the tenons to the mortises.

Step 3. This simple form will hold the wood at the right angle relative to the table saw blade.

Step 4. The curved leg is held in the form with hot glue.

Step 5. This concave jig is used to cut the top of the leg to the proper angle and length.

Step 6. Set the blade height for sawing one shoulder of the tenon.

Step 7. Use the convex jig to support the leg while cutting the tenon shoulders. The jig is used to cut the first shoulder of each tenon. Put the fence on the other side of the blade to cut the second shoulder.

Step 8. After sawing the tenon shoulders, turn the jig on its side to cut the tenon cheeks.

Step 9. Use a saw and a chisel to finish the tenon.

Step 10. After fastening the legs on with glue and screws, the carcass is ready for the drawer and doors to be fitted.

Figure 7-37. One method for making a slot for a panel to fit into a curved door rail involves incorporating narrower layers within the lamination that equal the thickness of the panel.

Make the Drawer

To make the drawer, begin by re-sawing the laminations for the drawer front on the band saw using a point-stile fence. The laminations can be planed smooth in the planer and then glued together in the same form as the curved face frames and door rails were. Smooth the edges of the drawer front on the belt sander and cut it to length (**Figure 7-36**).

Assembling the Doors

The final parts of the cabinet are the curved doors. The panel may spring back a bit, but it will conform to the frame's curve during the door assembly process.

There are two methods for making a slot for a panel to fit into a curved door rail. The first method, shown in **Figure 7-37**, is to build into the door rail lamination some narrower layers that equal the thickness of the plywood panel. This method can be used for irregular and S-shaped curves. The other method, routing the slot, is shown in "Cutting the Doors" on page 165.

DEMONSTRATION PROJECT: Making the Drawer

Now we're ready to cut and fit the drawer to the cabinet. Mill the drawer sides to the same thickness as the dovetail bit being used, in this case ½" (12mm). The side will fit into the front with a sliding dovetail joint.

Step 1. I made a curved-top sled to hold the drawer front when cutting the sliding dovetail. The sled rides in the miter gauge slot on the router table. There is a stop block clamped to the router table to keep the slot from becoming exposed by cutting through to the top of the drawer front.

Step 2. I stopped the slot ¾" (20mm) from the top of the drawer front. For any sliding dovetail, it is a good idea to cut the bulk of the material out with several passes of a straight cutting bit, and then cut the dovetail slot in one final pass.

Step 3. Use the same dovetail bit to cut the male side of the joint by standing the drawer side on end and passing it along a fence.

Step 4. Be sure to mill extra stock the same thickness as the drawer side to use for setting up the bit and the fence. The side should fit into the front without requiring excessive force and without flopping back and forth.

Step 5. Cut the slot for the drawer bottom into the curved drawer with a wing cutter on the router table. The oversize nylon bearing cover is ideal to keep the cutter from going in too deep.

Step 6. Rout the slots for the drawer runners and bottom, then glue up the drawer.

DEMONSTRATION PROJECT: Cutting the Doors

Use a rail-and-stile router bit set to create a strong joint in any door's corners and cut profiles along the frame's inside edge. Two types of these bits are commonly sold. The most common has two sets of cutters. One shapes the convex beading and the slot for the panel along the frame pieces. The second set shapes the ends that join the stiles. The second type makes both of these cuts using one set of cutters.

Step 1. Make a slot along the length of the curved rail by creating a curved fence for the router table that has the same radius as the rail. Then, use a straight cutting bit to cut the slot. The decorative ogee trim that goes around the inside of the frame will be added later.

Step 2. To join the stiles and rails at the corners of the doors and add a decorative trim around the frame's inside, use a rail-and-stile router bit.

Step 3. I used one-bit cutters to make the stiles and rails. For a curved rail, I ran the rail through the cutters with the concave side down. I made a crosscut sled to hold the rail in place as it was cut. I cut the rail first and adjusted the cutters to cut the stile to fit.

Step 4. Make a cove cut on the table saw by passing the rail over the blade perpendicular to the normal way wood is cut. When making rails for a curved door, save labor by cutting a cove on the underside of the rail before cutting the joint.

Step 5. It also will help to create a cleaner joint where the rail and frame meet if the inside of the frame and the end of the rail are slightly angled. The face of the edge of the stile will need to be flush with the fence as it is being cut.

Step 6. A piece of thick veneer or a thin strip of wood should work to elevate one edge of the stile to keep it in proper orientation to the cutter as it passes along the fence.

Gluing the Doors

Gluing up a curved panel can be tricky, but the same principles that apply to flat panels apply here. The stiles should be cut a little longer so they extend beyond the rails. They can be trimmed off flush after the glue has dried. Be careful to make the panel square, and checking it by measuring the diagonal dimensions **(Figure 7-40)**.

The outside of the stiles can be rounded to shape using a hand plane and then smoothed with a sander **(Figure 7-41)**. The inside curve of the stiles can be refined with a cabinet scraper and sanded (**Figure 7-42**). The panel is ready for finish sanding **(Figure 7-43)**.

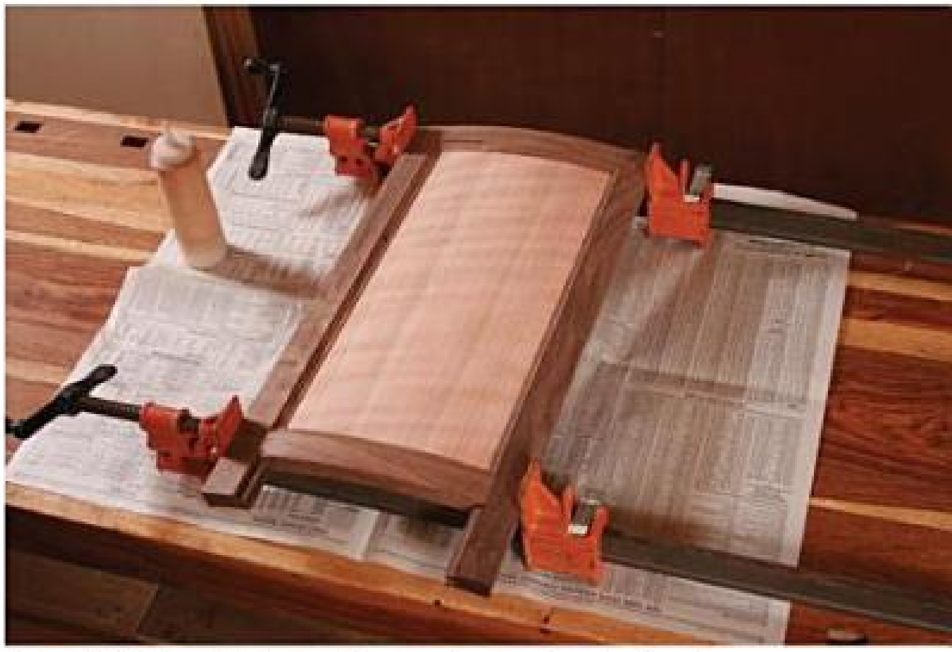


Figure 7-40. Check that the panel is square by measuring the diagonal.

Figure 7-41. Use a hand plane followed by a sander (right) for the outside of the stiles.

Figure 7-42. Smooth the inside of the stiles with a cabinet scraper and sandpaper.

Figure 7-43. The panel is ready for finish sanding.

CHAPTER 8

Finishing the Edges of Bent Panels

If you are building a project using veneered bent panels, one of the considerations will be how to finish the edges of the panels, especially if glue lines are visible (**Figure 8-1**). As I mentioned earlier, you can almost hide glue lines when working with dark-colored wood, but light-colored wood tends to show glue lines no matter how carefully the panels are constructed. To create a pleasing design, the edge of the panel will usually need to be covered or painted, or the panel can be placed inside a frame. In this chapter, I'll show you some of the different ways you can complete bent-panel edges.

Figure 8-1. Glue lines along panel edges should be finished or hidden for a more pleasing look.

Considering the Options

Especially when working with curved panels for furniture parts, such as legs or table bases, the easiest solution is to construct the panel using material that will look good when its edges are exposed. There are, however, few materials that will bend easily and, at the same time, look good enough to be exposed by blending with, or complementing, the surface material.

Another easy solution applies to panels used in cabinetry. Curved panels are usually placed inside a curved frame and are therefore hidden, as shown in the curved cabinet project in Chapter 7, "Bent Panels," on page 135.

For architectural applications such as curved-wall panels, molding can be placed around the panel both to create a decorative detail and cover the edge of the panel. For these applications, the panel is sometimes constructed of bending plywood or Kerfcore, bent right on site, and then surrounded by trim.

For a variety of projects, a solid-wood edge could be applied to the edge of a gently curving panel, but this process gets difficult quickly, as the radius of the panel tightens, as the panel tapers, or if edge of the panel curves inward along its length (**Figure 8-2**). Applying a solid-wood edge to a curved panel also gets more complicated if you are working with a compound curve, such as an S curve.

The first solution most people come up with is just to paint the edge. It seems like a good idea because the paint can be of any color that will complement or contrast with the surface veneer. However, because the edge is made up of layers, the glue lines between the layers will quickly show through the paint, leaving a series of hairline cracks along the length of the panel's edge. Because I like the look of a painted edge, the solution for me is to cover the edge with veneer and then paint it (**Figure 8-3**).

Wood-Bending TERMS

Hammer veneering. Applying veneer to a surface or panel without clamps, instead using an iron to set the glue and a veneer hammer to press the veneer down.

Veneer hammer. A tool that resembles an ax but has a blade at 90° to the handle and a cutting edge that's rounded instead of sharp.

Figure 8-2. A solid-wood edge can be applied to the edge of a gently curving panel, but the process gets difficult quickly if the radius tightens or if the edge of the panel curves inward along its length.

Figure 8-3. One way to cover bent-panel edges is to veneer them and then paint them.

A veneered edge also can be left natural so it looks like solid wood. To create the illusion of a solid board, the veneer applied to the edge can match the surface veneer (**Figure 8-4**). I also like to round the edge to create a bull nose, which I think creates a unity with the curved shape of the panel. It may sound complicated to apply veneer to a bull-nosed edge of a panel with a compound curve that might also taper in toward the center, but it isn't. Once you get comfortable using the process known as hammer veneering, you will be able to cover almost any edge with veneer.

Figure 8-5. A veneer hammer is specifically designed to apply a tremendous amount of pressure at the point of contact as it slides over the surface of the veneer.

Figure 8-4. You can make the edge look like one solid board by applying veneer that matches the surface veneer.

Hammer Veneering Bent-Panel Edge

I first learned hammer veneering from the old-world master craftsman Tage Frid. In the old-world method of hammer veneering, hide glue was melted and then brushed onto the veneer and the surface to be covered, and then the parts were placed together. Next, heat was added using an iron, and the veneer was pressed down with a veneer hammer. The veneer hammer resembles an ax with a blade at 90° to the handle and a cutting edge that's rounded instead of sharp (**Figure 8-5.**). The tool applies tremendous pressure at the point of contact as it slides over the veneer's surface.

Hide glue is made from animal hide, bones, and blood so the smell of it being heated is unpleasant. Because hide glue is organic material, it will eventually break down, particularly when it's exposed to heat or moisture. One day, I was hammer veneering the edge of a panel in my shop and becoming frustrated with the smell of the sticky glue that was everywhere. My shop-mate suggested I use a PVA glue instead of hide glue because PVA glues are thermoplastic and can be melted and reset with heat. He had been using a similar technique to cover the flat edges of plywood shelves for cabinets. After a little trial and error, I was quickly able to master the process, and have used it ever since.

Preparing the Edge

Shape the edge before applying veneer. If the panel has a flat edge, it can sometimes be cut to size on the table saw or sanded with a stationary sander or a handheld belt sander. If the panel has more of a curve or if it tapers down in size toward the center, the shape of the panel can be cut out with a band saw, jig saw, or handsaw (**Figure 8-6**). The edge can be cleaned up on a router table, as long as the edge of the panel can make contact with the fence along the entire length of the cut. A file, rasp, or hand plane also can be used to smooth the edge of a curved panel.

To determine the shape to cut out a bent panel, you can make a thin, flexible pattern, place it on the panel, and draw around the pattern. Another option is to use transparent tracing paper. Trace over the original drawing, attach the tracing paper to the panel, and follow the line when cutting the panel to size. A third option is to draw the outline of the shape you want to cut out right onto the panel. I prefer cutting out the shape on the band saw.

Figure 8-6. A panel can be cut to shape using a band saw.

In most cases, I round over the edges of the panel to produce a bull-nosed edge, which creates unity with the curved shape of the panel. The edge can sometimes be rounded using a router and a round-over bit. There are three problems with this technique, however. First, most routers have a flat base so they will not be able to reach inside many tight-radius curves or compound curves. Second, it is difficult to keep the router at exactly the same angle in relation to the face of the panel along the entire length of the cut, which is necessary for a uniform edge. Third, the bearing on the bottom of the router bit will inevitably burn or wear a line into the veneer along the edge of the panel. For these reasons, I usually shape the edge of a curved panel by hand.

Figure 8-7. A Surform or a rasp can be used to shape a bull-nosed edge on a curved panel. Sight down the edge of the panel to see if the shaped edge looks good.

The edge of a bent panel with even the most complex curve can easily be rounded over with a rasp, spokeshave, or sure form (**Figure 8-7**). I usually sight down the edge from a distance and from different angles to be certain the edge is even. The edge can then be further refined with a fine rasp or file and smoothed out with sandpaper. The edge is now ready to be hammer veneered.

Figure 8-8.
To repair a loose spot, you can cut a slit with a knife and use a scrap of veneer to push glue into it.

Troubleshooting with Hammer Veneering

There are a few common problems you may encounter when hammer veneering for the first time. I recommend trying this procedure on a straight and flat edge before progressing to curved and rounded edges. The most common problems are too little or too much glue or failure to let the glue dry long enough before pressing it down.

Make sure the glue on both surfaces has dried all the way through before applying the edge veneer. The glue on the veneer usually will take much longer to dry than the glue on the edge of the panel. If you hear a boiling sound when you place the iron on the surface, either there is too much glue or the glue is not dry enough. The glue should easily melt and stick without a lot of boiling or sliding around.

Too much heat can also be a problem because the glue can boil away and dry out completely. In this case, the veneer will be blackened and dry, and it still will not be attached to the surface. If the veneer is not too burned, you can reapply glue to both surfaces, let it dry, and iron it down again.

You may also encounter small spots where the veneer did not adhere properly. To find loose spots, tap on the surface of the veneer. If you hear a hollow scratching sound, it is a sign of a loose spot. If you hear a solid knocking sound, the veneer has adhered properly. If adding more heat doesn't do the trick, a little more glue can be applied under the veneer's surface, and be allowed to dry. The veneer can then be ironed down again. To get glue under the veneer, either:

- force a little glue under the surface from the edge where the surface veneer and the edge veneer meet or

- make a cut along one edge the length of the loose spot with a knife and then work the glue underneath with a piece of veneer, a palette knife, your finger, or air pressure (**Figure 8-8**).

Allow the glue to dry and then iron it down with the tip of an iron, being careful not to loosen the veneer around the loose spot.

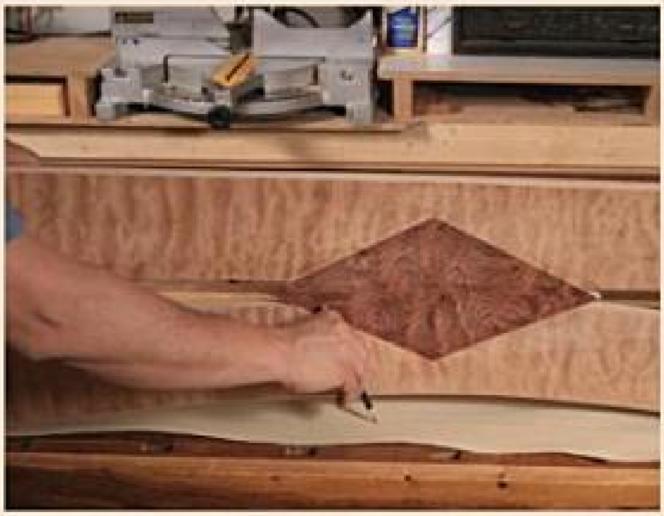
STEP-BY-STEP: Hammer Veneering an Edge

Two notes about edge veneers:

1. If you want to create the illusion of a solid panel, use some of the same veneer used to cover the surface for the edge.

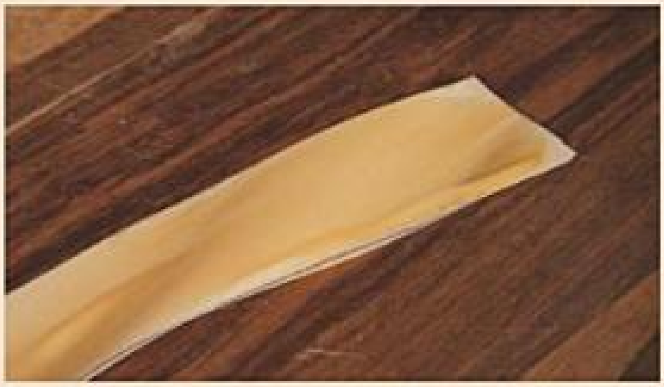
2. If you are going to paint the edge, use a veneer for the edge that is either close in color to the surface veneer or close to the paint color to be used.

Some types of veneer are much easier to curve and stretch around a curved edge without cracking than others. Veneers that work well for hammer veneering curved edges include poplar, walnut, and mahogany. For this demonstration, I used poplar because the color is close to that of the maple surface veneer and also because poplar is one of the easiest veneers to hammer veneer over complex edges.



Step 1. Place the curved panel on edge over the veneer to be applied to it and trace the shape. The veneer should be about ½" (12mm) oversize on each side.

Step 2. Cut out the veneer using a sharp knife. Then, spray distilled water on the surface that will be up and away from the glue. Immediately cover the other side with a thin film of glue. Moisture on both sides of the veneer will keep it from curling.



Step 3. Cover the surface evenly with glue. Set the veneer aside to dry and apply the same amount to the panel's edge. Allow the glue on both surfaces to dry thoroughly—usually 30 to 60 minutes. You should be able to run a finger over the surface without it sticking. The glue should change from yellow to light brown.

Step 4. Place the panel in a vise or secure it with clamps to a bench so you can work on the entire edge. Center the veneer over the edge and apply heat with a hot iron to the top of the bull-nosed edge at one end of the panel.

Step 5. Move the iron back and forth over the first 8" (20cm) to 10" (25cm) of length until the glue first softens and then begins to harden up again. Remove the iron and apply pressure to the surface using the veneer hammer.

Step 6. Push and pull the veneer hammer over the heated surface until the glue sets. Repeat on one side of the bull-nosed edge along the same 8" (20cm) to 10" (25cm). Don't worry if you can't get it to where the surface veneer meets the edge, because it will be completed later. Repeat the process for the next section and then again until you reach the end of panel.

Step 7. It may be difficult to get the edge veneer to stretch out and lie down on the inside of the curve. In this case, make a series of relief cuts with a knife or scissors. Now the veneer can be trimmed and cleaned up, and the seam where the surface veneer and the edge veneer meet can be closed.

Step 8. Use a chisel with the bevel riding on the surface of the panel to trim the edge veneer to within about 1/16" (1.5mm) of the surface on both sides along the length of the panel. Be aware of the grain direction of the veneer and follow the grain away from the panel to prevent the veneer from being pulled off the edge.

Step 9. Heat the glue right along the edge where the surface veneer and the edge veneer meet for a length of about 12" (30cm) to 15" (38cm). Then, press the veneer down with the veneer hammer. Look carefully to make sure the seam is tight before moving on.

Step 10. The edge veneer can be trimmed flush with the surface with a cabinet scraper or sandpaper. Again, follow the grain to prevent the veneer from being pulled off the edge.

Appendix 1

Glossary

Adjustable end blocks. Blocks of wood on both ends of a compression, or bending, strap that keep end pressure on the wood piece as it bends.

Air-dried. Wood that has been allowed to dry without additional heat, such as in a kiln. The moisture content of air-dried wood is often higher than that of kiln-dried wood.

Anvil. A hard metal surface used as a support on which projects can be hammered.

Architectural millwork. Shaped wood parts that are used in house and building construction, such as trim and molding.

Backer board. *See* Backing board.

Backing board. A board placed under a thin strip of wood as it is passed through a planer. Also called a backer board.

Bending by hand. Bending wood without the aid of jigs or presses and often without added moisture.

Bending iron. A commercially available or shop-made device with a variable heat source applied to a curved surface that the wood can bend around.

Bending machine. A heated curved form with movable clamps and metal cauls used to form the curved sides of a guitar.

Bending strap. *See* Compression strap

Bent lamination. Taking several layers of thin wood, each of which is thin enough to bend on its own, or with the added moisture of an adhesive, and gluing them together in a curved form.

Billet. A rough-sawn or split piece of green wood that is ready to be air-dried or is already air-dried.

Blanket. A wide, flexible pad that evens the pressure and spans the distance between the ribs of a bending form to make a smooth surface for a panel to rest on.

Book-match. Consecutive leaves of veneer joined so the front side of one sheet butts to the back of the next.

Bull nose. The rounded edge of a panel.

Calipers. A device with two movable arms used to measure the thickness of an object.

Cantilever. A piece of wood attached to the fixed side of a form that extends out over the movable side to keep it from rising up.

Caul. A piece of rigid material used to help clamps and forms apply even pressure to wood laminations.

Cleat. A block of wood attached to the bottom of a form so it can be clamped in a vise.

Compass curve. A curve that is part of circle and can be made using a compass or traced from a round object.

Compression strap. A metal strap placed on the outside of a curve, with blocks that fit against the ends, to keep the wood fibers in compression to help prevent the wood from splitting and cracking. *Also* called a bending strap.

Cove cut. A concave-shaped cut made along the length of a piece of wood on the table saw.

Cross band lamination. *See* Cross-grain lamination.

Cross cut. To cut wood across the grain.

Cross-grain lamination. Layers of wood that are glued together with the grain direction of each layer opposed to the grain direction of the previous layer. *Also* called crossband lamination.

Delamination. The separation of the layers within a plywood panel.

Felling lumber. Cutting down a live tree to harvest the lumber.

Flange. A metal fitting used to attach the end of a round pipe to a flat surface.

Flitch. A stack of veneer sheets sliced from a log and kept in sequential order so the grain and figure match from one leaf to the next.

Following bit. A router bit that cuts a piece to the shape of a pattern by means of a bearing that rides on the edge of the pattern.

Glue lines. The lines visible on the edge between each layer of a laminated piece.

Grain run-out. Wood grain that travels through the outside surface of the bend and is likely to split at the point where it breaks the surface.

Green wood. Wood that was recently alive and hasn't dried.

Guide strips. Strips that keep both the form and laminates from sliding around.

Hammer veneering. Applying veneer to a surface or a panel without clamps, using an iron to set the glue and a tool called a veneer hammer to press the veneer down.

Heating. Bending wood by adding heat, such as with a bending iron.

Inlaid veneers. A veneer made by placing one veneer over another, cutting through both, and then placing the top veneer into the hole left in the bottom veneer.

Inside form. A bending form used inside a vacuum bag.

Inside technique. A technique using a vacuum press in which both the wood and the form are placed inside the vacuum bag.

Interlocking grain. Grain in wood that travels in differing directions in relation to the surface of the wood.

Kerf. The width left by the saw blade as it cuts through wood.

Kerf-cut material. A panel created by partially cutting through one side of the panel in a pattern of parallel lines to allow the panel to bend easily while the remaining material gives the panel structural integrity.

Kiln-dried. Wood that has been dried in a kiln, usually to about 6% to 9% moisture content.

Laminates. *See* Laminations.

Laminations. Layers of wood that, when placed together with glue in between them, make up a curved shape that is called a bent lamination. *Also* called laminates.

Lignin. A flexible, glue-like chemical in wood that, when wet, allows wood to bend and, when dry, gives wood rigidity.

Manufactured kerf-cut sheet goods. A manufactured sheet material that has a series of cuts along its length. The cuts allow the material to flex across the width.

Marking gauge. A tool with an adjustable stop and a pin or cutter used to make a mark an even distance in from the edge along the length of a board.

Matched veneers. A veneer made by slicing wood into thin layers and then opening two sequential sheets like a book to create a mirror image.

Medium-Density Fiberboard (MDF). A composite sheet material made from sawdust and glue.

Moisture content. The amount of water present in wood.

Ogee. A gentle curve shape with a convex curve above and aconcave curve below that is often used as trim or along the edge of a piece of wood.

One-part ribbed form. A one-part form made of evenly spaced ribs that can be used to form laminated bent panels inside a vacuum bag.

One-part solid form. A block of wood with one curved side for the wood to bend around. They are made of layers of wood.

Open time. The time you have from applying the glue until it starts to stick. *Also* called working time.

Organic curve. A variable or undulating curve that cannot be made using a compass. Organic curves are similar to those found in nature.

Outside technique. A technique using a vacuum press in which the wood is placed inside the vacuum bag but the form remains outside.

Pass-through inlay. A shape made of contrasting wood that appears to pass through a panel.

Platen. A flat sheet of melamine with a grid work of channels for the air to flow from a vacuum bag.

Plywood. A composite material made of an odd number of layers that alternate in grain direction to resist wood movement.

Polyvinyl Acetate Glues (PVA). Water-soluble glues commonly used for woodworking projects.

Pre-bend. To bend a stick in a thick area or in an area where the radius will be small before bending the entire stick to create an even overall bend.

Pre-bending. *See* Pre-bend.

Rail. The horizontal member of a frame that fits in between the two vertical members, which are known as stiles.

Recurved bow. The type of bow that curves backward at the ends.

Registration marks. Marks placed on a piece of wood before it is cut up that allow the individual pieces to be put back together in the same arrangement they were before they were cut.

Resaw. To split or cut thinner boards from a thicker board.

Resin-impregnated honeycombed sheets. A material whose core consists of a network of resin-impregnated paper that is arranged in a honeycombed pattern.

Rheostat. An electronic switch that regulates the flow of electricity.

Glossary continued

Ribbed form. A ribbed form is constructed of individual ribs spaced between 2" and 6" apart. This lightens up the form and makes it ideal for making bent panels. Ribbed forms can be made of one or two parts.

Rip fence. A guide attached to a saw that helps cut an even amount from the length of a board.

Rip. To cut wood with the grain.

Riving wood. Cutting or splitting wood from the length of a log, preferably starting at a natural crack.

Rustic-style. An unrefined style of furniture that often incorporates sticks and rough-cut lumber.

Seasoned wood. Wood that has been air-dried to a moisture content of about 12%.

Shoot. To smooth out the edges of veneers in order to create a tight seam between two adjoining pieces.

Shooting. *See* Shoot.

Skin. The smooth outer layers of a bent panel that cover the rough interior layers.

Sled. A sliding table or box that holds a piece of wood at a certain angle as it is being cut or shaped on a machine.

Solid form. A form used for solid-wood laminations, steam bending, and some narrow panels. There are two types of solid forms: the one- and two-part.

Soundboard. *See* Sounding board.

Sounding board. The top or front surface of an instrument over which the strings lie. *Also* called a soundboard.

Springback. The tendency of bentwood to return to its original shape.

Stair stringer. A support than runs the length of a stairway and holds all of the steps in place.

Steam bending. Using steam and heat to bend wood, often through the use of a steam box.

Steam box. A container built to allow steam to surround and moisten wood.

Stile. One of the vertical sides of a frame that run the entire length of the frame with horizontal rails running between them.

Substrate. The base panel to which veneers may be glued. To avoid warping, the substrate must be veneered on both sides, not just one. Contemporary substrates most often are made of plywood or MDF.

Symmetrical design. A design whose sides are mirror images of one another.

Teeth per inch (TPI). A number that signifies how many teeth per inch a blade has. Fewer teeth per inch typically means easier sawdust removal and less burning of the wood.

Thermoplastic adhesives. Adhesives that dry by evaporation, when molecules of water are released.

Thermosetting adhesives. Adhesives that dry by chemical reaction that occurs when two parts are combined, when water is added, or when heat is applied.

Tonewood. Wood that produces a good quality of sound.

Two-part ribbed form. The same as a one-part ribbed form, except with male and a female sides. This type of form can be used in a veneer press or clamped with thick cauls to distribute the pressure evenly when a vacuum press is not available.

Two-part solid form. The same as a one-part solid form, except with male and female sides.

Vacuum press. A press that derives its pressure from the atmosphere around it after all of the air is removed from the vacuum bag.

Veneer. A thin slice of wood.

Veneer hammer. A tool that resembles an ax but has a blade at 90° to the handle and a cutting edge that's rounded instead of sharp.

Veneer press. A screw press that consists of several coarse-threaded clamping screws mounted in a stout wood or steel frame that is tightened down over the work. A veneer press is used in conjunction with a curved form and cauls tailored to the work.

Veneer shooter. A tool that consists of two straight edged boards that are stacked together. The veneers are stacked between the two boards so the edges that need to be smoothed out, or shot, are over each other and cut down even with the boards.

Wattage capacity. The amount of current that can safely flow through a wire, a switch, or any other electronic device.

Working time. *See* Open time.

Appendix 2

Resources

A & M Wood Specialty
357 Eagle Street North
P.O. Box 32040
Cambridge, ON N3H 5M2
Canada
(519) 653-9322
800-265-2759
www.forloversofwood.com
Thick veneers

B&B Rare Woods
4581 South Queen Street
Littleton, CO 80127
303-986-2585
www.wood-veneers.com
Veneer

Certainly Wood
13000 Route 78
East Aurora, NY 14052-9515
716-655-0206
www.certainlywood.com
Veneer

Erath Veneers
160 Industrial Avenue
P.O. Box 507
Rocky Mount, VA 24151
www.erathveneer.com
Veneer

Hearne Hardwoods
200 Whiteside Drive
Oxford, PA 19363
888-814-0007
www.hearnehardwoods.com

Highland Woodworking
1045 North Highland Avenue Northeast
Atlanta, GA 30306
800-241-6748
www.highlandwoodworking.com
Veneering supplies

John Wilson
406 East Broadway
Charlotte, MI 48813
517-543-5325
ww.shakerovalbox.com
Copper tacks.

Lee Valley & Veritas
P.O. Box 1780
Ogdensburg, NY 13669-6780
800-871-8158
www.leevalley.com
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Luthier's Mercantile International
7975 Cameron Dr., Bldg 1600
Wndsor, CA 95492
800-477-4437
www.lmii.com
Side-bending machines for guitars and other instrument-making supplies.

Oakwood Veneer Company
1830 Stephenson Highway
Troy, MI 48083
800-426-6018
www.oakwoodveneer.com
Paper-backed veneer sheets

Rockler Woodworking and Hardware
4365 Willow Drive
Medina, MN 55340
800-233-9359
www.rockler.com
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Treefrog Veneer
39 O'Neil Street
Easthampton, MA 01027
800-830-5448
www.treefrogveneer.com
Made-made veneers

Vacuum Pressing Systems
553 River Road
Brunswick, ME 04011
800-382-4109
www.vacupress.com
Vacuum press and veneering supplies

Veneer Systems Inc.
100 River Rock Drive
Suite 104
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800-825-0840
www.veneersystems.com
Vacuum press and veneering supplies

Veneer Supplies.com
www.veneersupplies.com
Forest Hills, MD
Veneer, vacuum press supplies

Woodcraft Stores
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www.woodcraft.com
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10320 Hickman Road
Des Moines, IA 50325
515-254-9494
www.woodsmithstore.com
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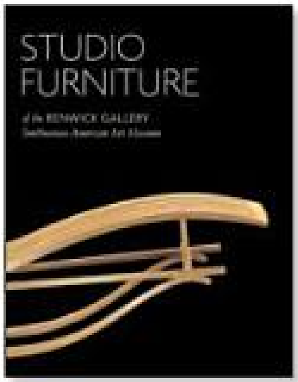

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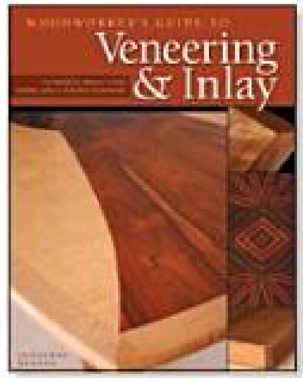

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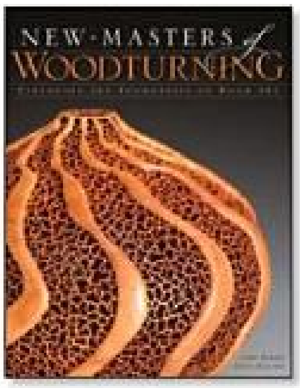

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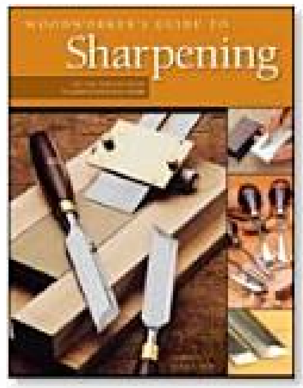

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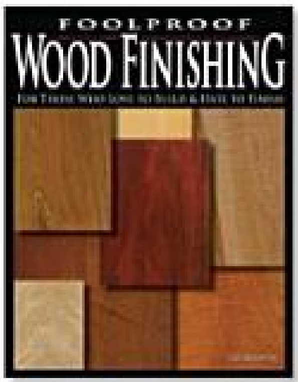

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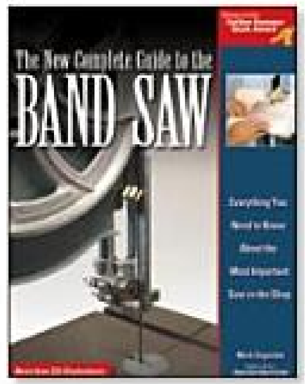

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